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4 Commercial Aircraft

4.1 Introduction

Two factors motivate the choice of commercial aircraft as the first case study of the techniques proposed in chapter 2. First, throughout the postwar era, and particularly between 1958 and 1972, profound quality changes occurred in both performance characteristics and operating efficiency of commercial aircraft. Second, a wealth of data is available on all aspects of the airline industry, as a result of its history of federal government regulation. The U.S. Civil Aeronautics Board (CAB) continued to collect the same continuous data base both before and after the passage of the airline deregulation act in late 1978, at least through the "sunset" of the CAB at the end of 1984, allowing the study in this chapter to cover the years 1947–83.[1] Among the relevant CAB data are the prices paid by airlines for each individual aircraft, and numerous details on operating costs and revenue-generating ability for each aircraft type.

The commercial airframe and aircraft engine manufacturers provide a case study of what was called in chapter 2 *nonproportional quality change*. With only a few exceptions, most new aircraft models introduced since 1958 have, in comparison with the preceding model, provided a percentage increase in net revenue exceeding the percentage increase in price. During the heyday of the transition from piston to jet aircraft, from 1958 to 1972, the relatively small extra price charged by aircraft manufacturers for new models resulted in the transfer of benefits from performance and efficiency gains to airlines

1. Much of the data base relevant for this study has been maintained since the demise of the CAB in the aviation public reference room at the U.S. Department of Transportation. In particular, a complete record is maintained of purchase prices of aircraft and aircraft engines and operating costs by airline and aircraft type, allowing the study reported in this chapter to be updated by future investigators.

and ultimately to airline customers in the form of a declining real price of airline transportation.

There can be no doubt in the case of the aircraft industry that changes in operating efficiency are viewed, along with changes in performance characteristics, as relevant dimensions of quality change. In 1982, fuel expenses represented between 38 and 57 percent of total operating expense for the fourteen major aircraft types operated by the domestic trunk airline industry (U.S. CAB, *Aircraft Operating Cost and Performance Report,* July 1983). Aircraft purchase decisions have involved trade-offs, widely discussed in the trade press, among price, performance, and operating efficiency. Airlines have been observed to incur substantial capital costs in order to replace one type of plane by another having no greater speed or carrying capacity, just to gain an improvement in operating efficiency.

The study in this chapter and that of electric generating equipment in chapter 5 are intended to provide examples of practical methods for implementing the rather general and abstract measurement framework outlined in chapter 2. The basic formula for quality adjustment (eq. [2.35]) requires the comparison of the observed change in the price of a new model with the extra net revenue that the new model provides relative to the old model, holding constant the prices of output and operating inputs. Because data on changes in net revenue are required, the airline and utility industries are ideal testing grounds for the methodology, since the government requires the publication of detailed information on operating costs of specific units of capital equipment. Changes in operating efficiency have been important for some other products, for example, automobiles and consumer appliances. While data on operating costs are available, there is no direct measure of "net revenue," and a different approach to quality measurement must be adopted.

The quality corrections suggested in this chapter are large in magnitude and primarily reflect the effect of jet technology in raising the ability of commercial aircraft to generate net revenue. Turbine engines produce greater thrust and faster speeds and have resulted in a quantum decline in the "real" unit costs of crew salaries, fuel cost, and maintenance. Crew costs declined, because jet aircraft produce many more seat miles per crew hour, and maintenance expenses declined, because jet aircraft typically fly at least twice as long between overhauls as piston engines, and failures between overhauls have become much less frequent (Straszheim 1969, 84). Decreased maintenance requirements have increased feasible daily aircraft utilization, although the estimates in this chapter err on the conservative side in calculating quality adjustments by attributing to piston aircraft the daily utilization achieved by jet aircraft in the mid-1960s.

The new estimates understate the "true" extent of quality change in another much more important way, and this is the choice of an aircraft seat mile as a homogeneous output "characteristic" over the entire postwar period. This ignores the value of time savings to passengers due to the fact that the introduction of the jet aircraft cut travel times roughly in half on given routes and made possible longer stage lengths that reduced the necessity for making intermediate stops. Less tangible dimensions of quality improvement, for example, elimination of piston-engine vibration, the ability of jet aircraft to fly above thunderstorms and reduce the incidence of turbulence, and the improved safety record of jet aircraft, are also ignored. But these additional aspects of quality change can serve as a counterweight to those who may find the large size of the basic quality adjustments difficult to believe.

The approach outlined in chapter 2 calls for a price index for identical models to be multiplied by a quality adjustment factor based on changes in net revenue relative to changes in aircraft purchase prices. The first step is the development of a price index for identical aircraft. Next are provided estimates of gross revenue, operating costs, and net revenue for pairs of aircraft. These pairs are new models and the old models they typically replaced on routes of approximately the same stage length (long haul, medium haul, and short haul). The resulting "adjacent model" net revenue ratios are then compared with purchase price ratios. The last step in the analysis is an examination of cross-model ratios of used aircraft prices at different points in time, intended to provide a check on the quantitative magnitude of the estimated cross-model quality differentials. The resulting used aircraft price ratios can be converted into a price index, and this confirms the previous suggestion that the net revenue method yields quality adjustments that are too conservative.

4.2 Postwar Performance of the Airline Industry

As a preliminary to the subsequent investigation, table 4.1 displays data on the postwar performance of the airline industry, exhibited as annual average growth rates over five-year intervals. The first three rows identify a sharp break in the relation between employment cost and productivity before and after 1972. In the twenty-five years before 1972, the average annual increase in employee compensation was 6.3 percent and that of productivity was 7.9 percent, so that unit labor cost declined by 1.6 percent per year. After 1972, however, productivity growth virtually ceased, indicating that the airline industry made its own contribution to the post-1972 "puzzle" of a productivity growth slowdown for the U.S. economy as a whole. Without productivity growth, most of the rapid post-1972 growth in employee compensation flowed down to row 3 to become a relatively rapid rate of increase in unit labor cost.

Shown in row 4 is the soaring cost of aircraft fuel resulting from the two OPEC "shocks" of 1973–74 and 1979–80. This followed a much slower annual increase in fuel cost of only 1.7 percent per year during 1947–72.

Table 4.1 **Airline Fares, Costs, and Productivity, Annual Growth Rates for Five-Year Intervals, 1947–82**

	1947–52 (1)	1952–57 (2)	1957–62 (3)	1962–67 (4)	1967–72 (5)	1972–77 (6)	1977–82 (7)	1947–82 (8)
1. Compensation per FTE employee	7.95	4.41	5.09	4.66	9.54	8.97	8.31	6.99
2. Output per FTE employee	9.67	8.05	5.47	6.68	9.76	0.45	1.31	5.91
3. Unit labor cost	−1.72	−3.64	−0.38	−2.02	−0.22	8.52	7.00	1.09
4. Fuel cost per gallon	4.08	2.82	−1.59	−0.28	3.64	24.36	22.92	7.52
5. Average operating cost	−1.83	−1.44	1.02	−2.36	1.15	7.85	10.53	2.13
6. Average passenger yield	1.87	−1.07	3.88	−2.83	2.29	5.99	7.54	2.52
7. BEA index of equipment cost	5.82	4.26	1.97	1.92	3.80	8.76	10.24	5.25
8. GNP deflator	3.18	2.34	1.67	2.30	4.80	6.96	8.12	4.20
9. Real average cost	−5.01	−3.78	−0.65	−4.66	−3.65	0.89	2.41	−2.07
10. Real average yield	−1.31	−3.41	2.21	−5.13	−2.51	−0.97	−0.58	−1.68
11. Real equipment cost	2.64	1.92	0.30	−0.38	−1.00	1.80	2.12	1.05

Sources by row: (**1, 2**) Compensation, from NIPA, table 6.5A, row 43. Full-time equivalent employees (FTE), table 6.8A, row 43. Output is measured by available seat miles for the domestic industry (trunkline and local service), from Bailey, Graham, and Kaplan (1983, apps. A and B). (**3**) Row 1 minus row 2. (**4**) 1965–82: U.S.CAB, *Aircraft Operating Cost and Performance Report,* various issues, price paid for jet fuel for all carriers operating narrow-bodied four-engine jet aircraft. 1947–65: PPI for refined petroleum products (index 07-5). (**5, 6**) Bailey,Graham, and Kaplan (1983, app. A). (**7**) This chapter, table 4.3, col. 3. (**8**) NIPA, table 7.1 (**9**) Row 5 minus row 8. (**10**) Row 6 minus row 8. (**11**) Row 7 minus row 8.

Average operating cost per available seat mile in row 5 shows an acceleration corresponding to that in labor and fuel cost, from an average of −0.7 percent per year in 1947–72 to 9.2 percent per year in 1972–82. Average yield growth accelerated less than growth in average cost, from 0.8 to 6.8 percent per year, providing an explanation of the sharp drop in operating profit margins (which were −5.9 percent in 1947, 5.8 percent in 1972, and −4.5 percent in 1982; Bailey, Graham, and Kaplan 1985, app. A).[2]

Equipment cost also displayed a post-1972 acceleration, although this was less marked than for operating cost, from an average in row 7 of 3.6 percent per year in 1947–72 to 9.5 percent in 1972–82. This acceleration was slightly sharper than for the GNP deflator (2.9–7.5 percent). It is interesting to compare the increase in equipment cost in row 7 with compensation per employee in row 1, in an attempt to determine indirectly the behavior of productivity growth in the aircraft manufacturing industry. This comparison is meaningful only on the assumption that employee compensation in the

2. The 1982 figure is for the twelve months ending 30 June.

aircraft manufacturing industry increased at about the same rate as in the airline industry (there is no separate BEA index for average compensation or productivity in the aircraft manufacturing industry, which is lumped together with automobiles and other components of "transportation equipment"). If profit margins were roughly constant, then differences between the growth rates of employment cost and the prices of aircraft provide an indirect measure of productivity growth in aircraft manufacturing. This difference was 2.7 percent for 1947–72 and −0.9 percent for 1972–82, an indirect comparison that would seem to indicate that, after 1972, productivity growth in the aircraft manufacturing industry was somewhat less rapid than in U.S. manufacturing as a whole. This conclusion is consistent with the increase in the real cost of aircraft relative to the GNP deflator displayed in row 11.

The figures displayed in table 4.1 raise a question about the sources of the rapid productivity growth in the airline industry achieved prior to 1972, as displayed in row 2, and the reason for the sharp post-1972 productivity growth slowdown. This experience was much more severe than for the U.S. economy as a whole, since productivity grew much more rapidly in the airline industry than in the rest of the economy prior to 1972, but more slowly thereafter. One possible explanation of rapid productivity growth in a particular industry or sector of the economy might be a decline in the cost of capital equipment at a rate greater than for the economy as a whole, inducing through substitution a greater rate of increase in real capital input than in the rest of the economy. However, this explanation does not appear promising for the airline industry, in view of the increasing real cost of equipment during the period of rapid productivity growth between 1947 and 1962, as shown in row 11.

A working hypothesis to be investigated in this chapter is that the official price index for equipment cost is incorrect, and that the true price of equipment decreased rapidly before 1972 in real terms, motivating airlines to purchase equipment and substitute away from labor and fuel toward capital. If this decline in the real price of equipment ended around 1972, at least some part of the productivity growth slowdown might be explained as the result of a lower incentive to substitute capital for labor. One possible reason for the official price index to have been more accurate after 1972 than before could have been a decrease in the importance of *nonproportional* quality change.

4.3 Index of Sale Prices of Identical Models

The existing national income accounts deflator for the aircraft category of purchases of producers' durable equipment, shown on row 7 of table 4.1, has been compiled by the CAB's Financial and Cost Analysis Division for the years since 1957. Airlines report purchases and retirements regularly for each individual aircraft in their fleet, and since these aircraft are identified on

CAB's Form 41 (Schedule B-7) by their month of acquisition and type (e.g., Boeing 707-331B), the CAB has been able to construct an aircraft price index by measuring the year-to-year change in the unit price for each type of equipment delivered in *both of two adjacent years*. Because only identical pieces of equipment are compared in adjacent years, the index ignores any "true" price change involved in the transition from one aircraft type to another. As an example, the substantial price reduction involved in the switch by Douglas in 1958–59 from the manufacture of the DC-7 to that of the DC-8 is simply ignored, and the price index for the year of transition is based only on price changes for planes that were manufactured in both the adjacent years. The CAB index, shown in column 3 of table 4.4, begins in 1957 and increases from 1957 to 1983 by 270 percent, somewhat more than the 232 percent increase in the GNP deflator.[3]

Even viewed on its own terms as a price index for identical models, the CAB index has weaknesses. First, its criterion of identical quality is that any aircraft with the same model number retains the same quality, no matter how long it remains in production: "The fundamental assumption is that any significant change in specifications for new equipment results in a change in the type or model number of the equipment as reported on CAB Form 41" (U.S. CAB 1977, 1). However, as we shall see below, significant quality improvements were made over the production lifetime of some major types of jet aircraft, for example, the Boeing 727-200. The second problem is that the CAB index measures price changes between adjacent years for a given model, without any attention to which airlines were purchasing that model. As we shall see, different airlines pay quite different prices for a given model in the same year, so that the price change measured by the CAB combines true price change with mix effects, as the weight of airlines paying relatively high and low price changes. A third problem, the fact that the CAB index extends back only to 1957 and leaves the 1947–57 decade uncovered, is sufficient to warrant an effort to construct an alternative price index for identical aircraft. However, in the process of constructing the alternative index, sufficient information has been gathered to allow an assessment of the first two problems as well.

Our index is based on unit prices of commercial aircraft, obtained from the same source as the CAB index, that is, CAB Form 41. To save time in copying the data, there was no attempt to look up the initial report of each aircraft purchase on Schedule B-7, since an inspection of forty of these quarterly forms would have been required just to cover a single airline for a single decade. Instead, the source of the price data is schedule B-43, which lists the complete inventory of aircraft owned by each airline at the end of each year, and shows acquisition year, serial number, historical cost,

3. The CAB index is extrapolated before 1957 by weighting together several components of the PPI unrelated to aircraft manufacture, including diesel engines and fabricated metal parts.

and number of seats. Because aircraft engines are not listed separately for each airframe and are not dated by acquisition year, the index covers only airframes. This should not be a major handicap, since aircraft engines have rather continuously represented roughly one-quarter of the value of the associated airframe. The forms used were those for 1961 (covering 1947–61), 1967 (covering 1961–67), 1973 (covering 1967–73), 1978 (covering 1973–78), 1982 (covering 1978–82), and 1983 (covering 1982–83).

Like the CAB index, the new index excludes leased aircraft and used aircraft. Another similarity is that only the domestic trunklines are covered, and local service carriers are excluded.[4] Coverage is also similar, with the new index having slightly greater coverage in 1958–67, and the CAB index having greater coverage in 1968–76.[5]

	Coverage as Percentage of Value of Aircraft Purchased by Domestic Trunk Carriers	
	CAB Index	Table 4.2, Column 4
1958–67	47.9	51.6
1968–76	70.4	58.2

The criterion for coverage is to include the seven largest domestic trunk carriers, American, Delta, Eastern, Northwest, Pan American, TWA, and United.

A basic decision in constructing a price index from the available data is whether to treat as identical all aircraft bearing the same model number or only aircraft of a given model number purchased by a given airline. In what follows, two indexes are developed, respectively dubbed the "same model" (SM) index and the "same model same airline" (SMSA) index. The importance of this distinction becomes evident in an examination of the raw data, which show, for instance, that in 1952 Pan American paid $1.27 million each for twelve DC-6Bs, almost 50 percent more than United's purchase price of $0.86 million each for eleven aircraft. A more recent example is Delta's purchase of five 727-200 aircraft in 1981 at an average price of $12.0 million, one-third more than American's purchase of ten 727-200 aircraft in the same year at an average price of $8.9 million. These discrepancies in purchase price reflect some unknown combination of

4. The CAB index for 1957–76, which is described in U.S. CAB (1977), covers only the domestic trunkline industry. Since then, airlines have been reclassified as "major," "national," and "regional," and in recent years the CAB index has included the first two categories.

5. The source for coverage of the CAB index is U.S. CAB (1977, table 2). My coverage is calculated as half the value listed in table 4.2, col. 2, divided by the total of aircraft acquired as listed in the same CAB table.

differing features and options on the aircraft itself, and differing contract terms (in the 1979–81 period, Delta's purchase price for 727-200 aircraft increased each year, indicating an escalated contract, while American managed to escape escalation).

The distinction between the two types of indexes can be illustrated with a simple numerical example illustrating the evolution of aircraft prices over a four-year period:

	Year 1	Year 2	Year 3	Year 4
Model 1, airline 1	1 @ \$1.00	10 @ \$1.00	10 @ \$1.00	1 @ \$1.00
Model 2, airline 1	5 @ \$1.00	. . .	8 @ \$1.21	5 @ \$1.32
Model 2, airline 2	. . .	7 @ \$1.32	. . .	10 @ \$1.58

Here, we have model 1, which is sold at the same price to airline 1 in each year. In the early years of jet aircraft, it was common for airlines to receive aircraft over a number of years on a single fixed-price contract, for example, purchases by Eastern, United, and American of Boeing 727-100 aircraft at a single price for each airline extending over the five-year period 1963–67. As for model 2, its price is assumed to increase at 10 percent per year. It is purchased by airline 2 only in years 2 and 4, while airline 1 does not purchase model 2 in year 2. Also, airline 2 for some reason pays 20 percent more for model 2 than does airline 1.

The CAB index is constructed for adjacent year pairs by using second-year quantity weights to construct a ratio of revenue in each year:

$$R_t = \frac{\sum_j P_{tj} Q_{tj}}{\sum_j P_{t-1,j} Q_{tj}} . \tag{4.1}$$

The price index that links together the R_t ratios is

$$I_t = 100 \prod_{k=1}^{t} R_k . \tag{4.2}$$

Just as the CAB index treats as a single homogeneous commodity any aircraft bearing a given model designation, regardless of which airline has done the purchasing, so we can construct an analogous SM index, and contrast it with an SMSA index. The alternative SM index differs from the CAB index only in the index number formula, which is based on the Törnqvist approach that applies value weights or logarithmic changes. The price change between two adjacent years is

$$(4.3) \qquad r_t = \frac{\sum_j (V_{t-1,j} + V_{tj})(\log P_{tj} - \log P_{t-1,j})}{\sum_j (V_{t-1,j} + V_{tj})},$$

where $V_{tj} = P_{tj}Q_{tj}$. The price index that links together these adjacent year changes is

$$(4.4) \qquad I_t = 100 \prod_{k=1}^{t} (1 + r_k).$$

The SMSA index is calculated with (4.3) and (4.4), differing only in that the index in (4.3) refers to a given model for a given airline, rather than a given model purchased by all airlines.

The difficulty in developing the SMSA index, which treats a given model purchased by different airlines as a different commodity, is evident in the numerical example. This more demanding criterion of quality homogeneity results in a drastic reduction in the sample of observations available, since no single airline purchased model 2 in adjacent year pairs 1 and 2 or 2 and 3. A straightforward calculation of the SMSA index would give a misleading result, since it would place no weight at all on model 2 in the first two year pairs. By placing all the weight on model 1, the resulting SMSA index would yield a zero rate of price change for the first three years, ignoring the increasing price of model 2.

A simple solution to this puzzle is to interpolate the observations for purchases of a given model by the same airline, "filling in" years with no purchases by interpolating between years when purchases were actually made. By interpolation, we can fill in the values of \$1.10 for model 2 and airline 1 in year 2, and \$1.45 for model 2 and airline 2 in year 3. The following table shows the results of applying these different index number methods to the example:

		Törnqvist Index		
Year	CAB Method (SM)	SM	SMSA Raw Data	SMSA with Interpolation
1	100.0	100.0	100.0	100.0
2	122.4	110.8	100.0	103.4
3	107.6	106.3	100.0	109.6
4	123.8	120.1	104.9	116.0

The SM indexes, whether constructed by the CAB or by the Törnqvist methods, exhibit a common zigzag pattern, jumping in years 2 and 4 while declining in year 3. This is strictly a mix effect and reflects the fact that the high-price airline 2 purchased model 2 in years 2 and 4 but not in years 1 and 3. Another feature of the SM indexes is that the CAB method registers a higher rate of price change. This results from the formula (4.1), which exaggerates price change by using the prior year price in the denominator, instead of the average of the current and prior year price,which would give a closer approximation to the theoretically preferable Törnqvist index formula (4.3).

The three Törnqvist indexes also differ. The column labeled "SMSA Raw Data" registers no price change in years 1 through 3, since it gives a 100 percent weight to the unchanged price of model 1 and no weight at all to the rising price of model 2. This occurs because there is no available comparison for model 2 in adjacent year pairs 1 and 2 or 2 and 3, because no single airline purchases that model in both those adjacent years. The column labeled "SMSA with Interpolation" provides the closest approximation to "what is really happening," that is, a steady price for one model and a price increasing steadily at roughly 10 percent per year for the second model. The rate of change of the interpolated SMSA index is 3.4, 5.8, and 6.0 percent in the three adjacent year pairs, with the differences reflecting only the relatively smaller number of model 2 aircraft sold in year 1. The only apparent defect of the interpolated SMSA index is an exaggeration of price change, due to the inclusion of interpolated prices (using prior year's sales as weights), which attributes to any model for which interpolated observations are used a higher weight than is warranted by actual sales.

Table 4.2 displays rates of price change for the two Törnqvist indexes, equivalent to the SM and interpolated SMSA indexes in the above example. The SM index treats a single model as a homogeneous commodity, regardless of which airline makes the purchase, and registers a price change when there is a change in the mix of airlines paying relatively high and low prices for the same model. In table 4.2, column 1 shows the total value of purchases in each adjacent year pair, for example, $2,659 million in the 1982–83 pair (listed by the second year, 1983, in the table). Column 2 displays the ratio of the value in column 1 to the total value of aircraft purchases in the PDE component of the NIPA. Since coverage in the new SM index and the CAB index is similar, the fact that coverage in the new index is in the 15–25 percent range must reflect categories of aircraft that are excluded from both the SM and the CAB indexes, including aircraft leased by trunk carriers, aircraft purchased or leased by other airlines, and all general aviation aircraft, as well as the fact that the new data exclude the value of engines while the PDE component of the NIPA includes them. Like the PDE component of the NIPA, the new index excludes exports and, at least in principle, includes imports (the only imported aircraft included in the sample is the Airbus A-300 during the years 1978–82).

As in the above example, the interpolated SMSA index treats as a homogeneous commodity a given model purchased by a given airline. Interpolated

Table 4.2 **Weighted Price Changes for Identical Aircraft**

	Adjacent-Year Pairs						
	Same Model (SM)		Same Model Same Airline (SMSA)			Weighted Percentage Change	
Second Year of Pair	Value of Aircraft ($ million) (1)	Percent of NIPA Value (2)	Number of Aircraft (3)	Value of Aircraft ($ million) (4)	Percent Value Interpolated (5)	SM (6)	SMSA (7)
1983	2,659	22	80	2,659	. . .	2.4	2.8
1982	673	4	24	597	. . .	15.1	11.2
1981	1,235	7	52	954	. . .	6.1	9.9
1980	1,774	14	98	1,611	. . .	11.0	10.1
1979	1,572	19	128	1,608	6	7.2	6.2
1978	1,105	22	109	1,178	9	11.0	9.2
1977	638	13	54	545	27	8.0	11.3
1976	613	16	79	865	49	−3.7	7.9
1975	1,041	24	94	1,236	31	8.2	6.5
1974	1,274	25	73	753	14	3.0	5.1
1973	1,260	26	69	935	. . .	5.3	3.6
1972	1,015	31	45	511	18	2.2	1.2
1971	1,296	35	106	1,399	7	4.5	4.2
1970	1,010	20	41	341	12	5.8	3.2
1969	817	13	202	854	8	1.2	2.5
1968	1,346	22	258	1,337	4	4.5	3.1
1966	921	30	191	830	25	1.4	0.8
1965	533	25	181	842	48	0.0	1.8
1964	146	11	97	496	66	0.7	2.0
1963	28	2	65	320	70	9.4	3.9
1962	232	15	62	266	58	−13.9	0.6
1961	594	37	152	653	27	1.3	−1.3
1960	781	48	147	549	18	−3.4	2.7
1959	244	20	85	208	. . .	9.2	0.4
1958	150	17	86	130	. . .	−0.9	−0.3
1957	179	20	110	170	5	1.7	0.7
1956	135	25	83	125	26	−3.9	1.6
1955	81	22	49	70	38	10.8	3.0
1954	54	13	56	57	19	8.5	6.7
1952	88	31	107	75	10	7.5	7.3
1951	21	13	29	24	3	−4.5	−3.6
1950	8	4	20	14	47	18.6	11.3
1949	33	19	44	23	44	3.2	6.7
1948	59	31	82	54	5	6.2	0.1

Sources by column: (1, 3–7) U.S. CAB, Schedule B-43, 31 December 1961, 1967, 1973, 1978, 1982, and 1983. See explanation in text. (2) Column 4 divided by the sum for pairs of adjacent years of private purchases of aircraft, NIPA, table 5.6, row 21.

purchase prices are created when a given airline purchases a given aircraft model in two years separated by one or more years when no such aircraft were purchased. The price attributed to these purchases is based on a linear interpolation of the prices paid in years when actual purchases were made, and the weight attributed to these purchases was a value equal to the interpolated prices times the quantity sold in the earlier year. As an example,

Table 4.3 **Ratios to SMSA Value without Interpolation**

	SM Value (1)	SMSA Value with Interpolation (2)
1948–57	1.28	1.22
1958–67	1.30	1.45
1968–77	1.40	1.19
1978–83	1.07	1.02

Source: Calculated from table 4.2, cols. 1 and 4.

TWA purchased two model 727-200 aircraft in 1969 at $5.0 million each and five in 1971 at $5.88 million each. A 1970 observation is created as two 727-200 TWA aircraft purchased at $5.44 million each. After 1966, it was necessary to create interpolated observations only for gaps of a single year. But in the early 1960s there was a substantial period between the initial purchases by trunk carriers of first-generation jet aircraft in 1958–61 and a second wave of purchases of the same models in 1966–68. In this period, interpolated observations are created to fill a six-year gap for the American Airlines 707-100B between 1959 and 1966, and a four-year gap for the United Airlines DC8-50 between 1961 and 1966.

In table 4.2, columns 3 and 4 exhibit the number and value of aircraft included in the interpolated SMSA index, including the value attributed to the interpolated observations, and column 5 displays the percentage of the weight in each adjacent year pair attributed to interpolated observations. In some years, no interpolation is necessary, while in other years, particularly 1949–50, 1962–65, and 1975–76, a heavy weight is given to interpolated observations. The effects on sample size of interpolation and of the distinction between the SM and the SMSA criteria can be summarized by expressing the average ratio of the values displayed in column 1 for the SM index and in column 4 for the interpolated SMSA index to the equivalent value for the SMSA index without interpolation, shown in table 4.3.

With the exception of the post-1977 period, when the effects on sample size of both interpolation and the SM-SMSA distinction are minimal, the effect of interpolation is to increase sample size by between 20 and 45 percent, and the effect of using the SM instead of the SMSA criterion (without interpolation) is to increase the sample size by between 28 and 40 percent.

The two final columns of table 4.2 display the weighted percentage price change for each adjacent year pair for both the SM and the interpolated SMSA index. Several periods (1959–60, 1962–63, 1976–77) display zigzag movements for price change in the SM index that are not present in the interpolated SMSA index and are analogous to the zigzag movements in the SM index calculated for the above example. The two series for price change are converted into index numbers (1972 = 100) and compared with

Table 4.4 **Price Indexes for Identical Aircraft (1972 = 100)**

	SM (1)	SMSA (2)	BEA (3)
1983	201.8	223.4	253.3
1982	197.0	217.3	247.8
1981	171.1	195.4	224.1
1980	161.2	177.8	204.3
1979	145.2	161.5	182.2
1978	135.6	152.1	163.6
1977	122.1	139.3	152.2
1976	113.1	125.1	138.8
1975	117.3	116.0	123.4
1974	108.5	108.9	115.2
1973	105.3	103.6	104.1
1972	100.0	100.0	100.0
1971	97.8	98.8	98.1
1970	93.6	94.8	94.0
1969	88.5	91.9	88.7
1968	87.4	89.7	85.6
1967	83.6	87.0	83.0
1966	80.9	86.9	80.0
1965	79.6	86.2	78.7
1964	79.6	84.7	77.1
1963	79.1	83.0	78.7
1962	72.2	79.9	75.5
1961	82.3	79.4	73.2
1960	81.2	80.4	72.3
1959	84.0	78.3	72.1
1958	76.9	78.0	69.6
1957	77.6	78.2	68.5
1956	76.2	77.7	65.2
1955	79.2	76.4	59.8
1954	71.5	74.2	57.5
1953	65.9	69.6	56.8
1952	62.5	66.4	55.6
1951	58.2	61.9	55.9
1950	60.8	64.1	49.0
1949	51.3	56.6	46.5
1948	49.7	54.0	44.7
1947	46.8	53.9	41.9

Sources by column: (1–2) Table 4.2, cols. 6 and 7. (3) NIPA, table 7.20, row 21.

the BEA aircraft deflator in table 4.4. The latter consists of the CAB index for the period after 1957 spliced for 1947–57 to a proxy index developed by the BEA that includes various PPI series unrelated to aircraft, including "fabricated metal products" and "diesel engines."

The implications of the three indexes displayed in table 4.4 for the long-run rate of price change in the aircraft manufacturing industry can be summarized by calculating average annual rates of price change for each decade through 1977, and for the period since 1977, seen in table 4.5. As shown in the bottom row, the average rate of price change of the SM and the interpolated SMSA indexes is virtually identical and is roughly 1 percentage

Table 4.5 Average Annual Rates of Price Changes for Identical Aircraft

	SM	Interpolated SMSA	BEA
1947–57	5.19	3.79	5.04
1957–67	0.75	1.07	1.94
1967–77	3.86	4.82	6.25
1977–83	8.74	8.19	8.86
1947–83	4.14	4.03	5.13

Source: Calculated from table 4.3.

point less per annum than that of the BEA index. In each of the four subperiods, the interpolated SMSA index increases less rapidly than the BEA index by a roughly uniform amount, between 0.67 and 1.43 percentage points per annum. The differential between the SM and the BEA indexes is more erratic, and the SM index actually grew more rapidly than the BEA index in the first subinterval, 1947–57.

4.4 Price Changes and Quality Improvements for Particular Models

To assess the slower rate of price increase registered by both the SM and the interpolated SMSA indexes as compared to the BEA index within the last decade, we can examine price changes on aircraft that were purchased by a single airline year after year. In the last half of the 1970s, Delta was the only major airline that purchased the same aircraft in numerous successive years. The following is a comparison of 1974 and 1982, chosen because Delta purchased the L-1011 and 727-200 aircraft in both years:

	($ million) 1974	($ million) 1982	1982/1974
Delta L-1011	15.9	31.3	1.969
Delta 727-200	6.7	13.0	1.940
Interpolated SMSA index	108.9	217.3	1.995
CAB index	115.2	247.8	2.151

My interpolated SMSA index is substantially closer to an average of the price increases registered by the two Delta aircraft than the CAB index.

The price increase registered on the Delta 727-200 is a particularly important cross-check of the two indexes, since that aircraft model represented the great bulk of the airline purchases by major airlines during the 1973–80 period, when the two indexes diverge. Another check is to take the average price paid by all airlines for the 727-200 in the first round of purchases (1969) and the last year in which several of the large airlines purchased the same model (prices are listed, with numbers purchased in

Table 4.6 **Average Price Paid by All Airlines for the 727-200**

	1969	1980	1980/1969
American	5.4 (10)	8.9 (4)	
Delta	. . .	11.6 (9)	
TWA	5.0 (2)	. . .	
United	5.2 (6)	10.6 (4)	
Weighted average for 727-200	5.3	10.7	2.019
Interpolated SMSA	91.9	177.8	1.935
CAB index	88.7	204.3	2.303

parentheses), listed in table 4.6. Here, too, the new index is closer to the increases in prices paid for the 727-200.

There is an indirect piece of evidence that the interpolated SMSA index may overstate price increases rather than understate them. The ratio of this index for 1978 to its value in 1967 is 1.75. This ratio, when multiplied by the $3.1 million price paid for a DC9-30 model in 1967, implies that the same model would have sold for $5.4 million in 1978. However, in that year, a stretched version of the same aircraft, having 27 percent more seats, the DC9-50, was sold for only $5.6 million. I conclude that the CAB index is biased upward in the late 1970s, even by its own criterion of measuring price changes of identical aircraft.[6]

A common weakness of all the price indexes discussed thus far, including the interpolated SMSA index as well as the CAB index, is the assumption that a given model designation, for example, Boeing 727-200, indicates homogeneous quality. However, this does not prove to be a warranted assumption. The Boeing 727-200 was produced for seventeen years prior to termination of production in 1983, the Boeing 737-200 was produced for seventeen years, and the Boeing 747-200 was still being produced in 1988 after sixteen years. During these long production runs, substantial changes were made to these aircraft. In fact, in the used aircraft market, B727-200 aircraft produced after 1974–75 are classified separately as "B727-200 ADV," standing for *advanced*. For each aircraft model shown in table 4.7, standard specifications are listed for both 1983 and the first year of the production run. In all cases, the 1983 version of the same model designation incorporates substantial improvements. Chief among these are improvements in engine thrust and fuel economy that allow the addition of more fuel and more seats to increase range, payload, and airline profitability. For instance, the stretched 727 models purchased by United in the late 1960s could not fly nonstop from Chicago to San Francisco, whereas the models delivered in the

6. A qualification to the comparisons in the text is that they do not include all aircraft manufactured during this period. The B-727, L-1011, and DC-9 accounted for 53 percent of the number of commercial aircraft sold in 1976–80 (*Aerospace Facts and Figures*, 1981–82 ed., 37).

Table 4.7 **Quality Changes on Boeing Aircraft Carrying Identical Model Numbers (prices include engines)**

	737-200		727-200		747-200	
	1968 (1)	1983 (2)	1967 (3)	1983 (4)	1971 (5)	1983 (6)
1. Engine thrust (pounds)	14,000	15,500	14,000	16,000	48,570	54,750
2. Gross weight	95,000	115,500	170,000	197,000	775,000	833,000
3. Range (nautical miles)	1,300	1,850	1,700	2,250	5,160	6,130
4. Standard seats[a]	101	110	139	156	395	452
5. Fuel burn (pounds/mile)	15.6	15.4	27.6	25.0	51.6	46.1
6. Fuel burn (pounds/seat/mile)	.154	.140	.199	.160	.131	.102
7. Theoretical 1983 price of configuration ($ million)	14.0	15.9	19.5	21.8	71.6	85.0

Source: Boeing Commercial Airplane Co., internal records, 1984.

[a]Seating configuration adjusted from Boeing data to hold constant the number of rows devoted to the first-class cabin.

late 1970s could do so. Full-sized 747-200 aircraft produced in the 1970s could not fly nonstop from New York to Tokyo, but those produced in the 1980s could do so (prematurely making obsolete the shortened 747-SP designed explicitly for those long routes). Also included on the newer versions (and not shown in table 4.7) are improved avionics that provide better navigation and flight management systems to achieve a flight path that is closer to optimal.[7] Aircraft models developed in the 1980s, especially the Boeing 767 and 747-400 (as well as the Airbus,which is foreign made and thus not relevant for the U.S. GNP deflator), have completely computerized cockpits with sophisticated self-diagnostic capabilities. For instance, a mechanic can now plug a computer terminal into an engine on a 767 and watch the engine diagnose its own problems.

Two figures are shown on rows 5 and 6 for the improvement in fuel efficiency. Row 5, showing fuel burned in pounds per mile, understates the improvement in efficiency, because the newer aircraft are able to carry a higher payload for a given amount of fuel. The second figure in row 6 shows fuel burned in pounds per seat mile and obviously improves more over the years, by 9.5 percent for the 737-200, 21.8 percent for the 828-200, and 25.0 percent for the 747-200. The increase in number of seats per aircraft shown in row 4 holds constant the 1983 mix between first-class and coach seating and calculates a hypothetical number of seats for the earlier year (by taking the actual earlier seating configuration, which in each case included a larger share of first-class seating, and converting sufficient rows of first-class seats to coach to achieve the same number of first class seats as in 1983). The total number of coach seats in 1983 is greater than in the earlier years for each aircraft, reflecting a combination of thinner seats (allowing more seats to be added without sacrificing leg room), less leg room, and higher aircraft payload capacity. The earlier version of the aircraft may have been physically capable of holding more seats than were actually used, but only by sacrificing range (increasing the number of passengers always results in decreased range for a given plane with given engines operating at a given gross weight, since more weight devoted to passengers means less weight can be devoted to carrying fuel). So, leaving aside a minor decrease in passenger comfort, the evidence of improved fuel economy in row 6 of table 4.7 is more relevant than in row 5.

The final row of table 4.7 shows a calculation by Boeing of the marginal cost of production of the 1983 configuration as compared to the earlier configuration. The figure shown for the earlier year is the 1983 price adjusted for the cost of the increase in the capability of the airplanes through changes in gross weight, range, engines, fuel consumption, and avionics.

7. All data in table 4.7 and in this section of the text were provided by W. G. Loeken of the Boeing Commercial Airplane Co. in several letters sent to me in 1984.

The improvements on the 737-200 are estimated to have added 13.5 percent to its price, as compared with 11.8 percent for the 727-200 and 18.7 percent for the 747-200. If we take an unweighted average of these three figures, 14.7 percent, we can calculate the implications for the price index of identical models. Assume that similar improvements were made to aircraft produced by other manufacturers, for example, the Douglas DC-9 and DC-10 and the Lockheed L-1011.[8] The period 1972–82 is chosen for comparison, since aircraft sales in this decade were dominated by the three Boeing models and the three other models produced by Douglas and Lockheed:

	1982/1972
CAB index	2.478
Interpolated SMSA index	2.173
SMSA index adjusted for 14.6 percent quality change	1.896

Thus, the CAB index exaggerates the 1972–82 price increase of commercial aircraft by roughly 30 percent. No information is available to assess the importance of this problem in earlier decades, but similar quality improvements may have been introduced over the lifespan of planes that remained in production for a decade, for example, the DC-6B and the Boeing 707-100B and 707-300B. The substantial number of aircraft that remained in production only for a short interval of three to five years, however, including the DC-7, the Convair 880, the Boeing 720, and the

8. The three Boeing aircraft dominated deliveries by the U.S. commercial aircraft industry during the 1972–80 period. The following figures are from *Aerospace Facts and Figures*, various issues, and are not available to me from the same source for years since 1980. These figures cover all aircraft manufactured in the United States, including exports and leased aircraft, and thus cover a larger universe than the SMSA or the CAB indexes in tables 4.2 and 4.4:

Share of Deliveries, 1972–80, Total U.S. Industry (percentage of aircraft produced by number, not value)	
1. Boeing 737	18.5
2. Boeing 727	36.6
3. Boeing 747	14.1
Total, rows 1–3	69.2
4. Lockheed L-1011	8.6
5. Douglas DC-10	7.5
6. Douglas DC-9	8.3
7. Other	6.4
Total, rows 1–7	100.0

Boeing 727-100, suggest that the "hidden quality improvement phenomenon" was probably less important in the 1950s and 1960s than in the 1970s.

4.5 Quality Adjustments Based on Net Revenue Data

The technique of price measurement proposed in chapter 2 adjusts price differences between models of a given product for changes in net revenue yielded by new models, because firms purchase capital goods for their ability to produce "net revenue" (defined as gross revenue minus operating costs—thus, net revenue is the amount available to pay depreciation and interest charges). Holding constant the prices of unchanged models, if a 10 percent increase in the price of new model B compared to old model A is accompanied by a 10 percent increase in net revenue, no quality adjustment is required to an index of the prices of identical models, like those developed in table 4.4. However, an increase in the net revenue provided by model B relative to model A that is greater than the excess of the price of model B over model A would call for a quality adjustment to the table 4.4 price index. To repeat equation (2.35) from chapter 2, the change in the *real* input price index ($\Delta p^i/p^i$) that holds constant the cost of producing identical models is

$$\frac{\Delta p^i}{p^i} = \left[\frac{v_1 n_0}{v_0 n_1}\right]\left[\frac{n_0}{n_1}\right]^{\alpha-1} - 1. \tag{4.5}$$

Here, v designates the purchase price of models 1 and 0, and n designates their respective net revenue.

If $\alpha = 1$, then the second term in brackets becomes unity, and the remaining expression states that the "real" price change will be zero if both purchase price and net revenue change in proportion in the shift to the new model, $(v_1/v_0) = (n_1/n_0)$. If the cost schedule that allows a manufacturer to produce a higher-cost model exhibits diminishing returns in the extra net revenue produced, then $\alpha > 1$, and the second term in brackets becomes a fraction less than unity. Why is the second term in brackets, the "curvature adjustment," required? In the presence of diminishing returns, a movement along a fixed cost function should yield a less-than-proportionate increase in n for a given increase in v, and the first bracketed term would erroneously register a price increase when in fact the cost function had not shifted. Imagine a downward shift in the cost function sufficient in the presence of diminishing returns to yield an increase in n proportionate to that in v. Again, the first bracketed term would erroneously register no change in price when in fact the cost function has shifted downward. Thus, the curvature adjustment corrects for the fact that, in the presence of diminishing returns in the production of n in response to increased v, the first term in brackets always overstates the real price increase.

The nominal input price index $\Delta p^i/p^i$ is then obtained by adding the increase in the real input price from (4.5) to the change in the price index for identical models ($\Delta C/C$). Copying (2.36) for convenience, we have:

$$\frac{\Delta P^i}{P^i} = \frac{\Delta p^i}{p^i} + \frac{\Delta C}{C}\,. \tag{4.6}$$

Thus, the purpose of this section is to develop measures of net revenue suitable for creating the year-to-year changes in the real input price index from equation (4.5). Subsequently, these changes will be added to the changes in the interpolated SMSA price index for identical models shown above in column 2 of table 4.4.

Any attempt to calculate changes in real input price using (4.5) will yield results that are sensitive to the assumptions made about expectations. In comparing a new and an old model at a particular time, the ratio of current-period prices (v_1/v_0) can be observed in a straightforward manner, but the ratio of net revenue (n_1/n_0) depends on expected output prices, expected output productivity, expected input prices, and expected input requirements, not to mention the expected lifetimes of the new and old models (the lifetime itself is an economic decision that depends on the unpredictable evolution of aircraft revenues and costs). A number of assumptions could be made about the revenue and cost calculations of users making aircraft purchasing decisions over the years, including static expectations, extrapolation of past trends, and expectations that are accurate *ex post*.

It would make no sense to proxy expectations as an extrapolation of past trends in the airline industry, since the introduction of the jet plane created a clean break with past operating conditions. Static expectations would also be a weak assumption, since labor expenses are a major component of airline operating costs, and wage rates have risen regularly every year (recall table 4.1 above).

The assumption that seems easiest to justify is accurate expectations *ex post*. In the analysis that follows, the sales price of a new model is compared with that of an old model (v_1/v_0) in the year of introduction of the new model. However, when possible, the ratio of net revenue for the two models (n_1/n_0) is calculated not only for that year, but also for several years in the future. The exact procedure is to calculate net revenue ratios for several years, starting with the year of introduction of the new model and continuing with years spaced five years apart (1967, 1972, 1977, etc.) until the date of retirement of the old model. Two factors prevent this procedure from being carried out for every model pair. First, the CAB operating cost data are not available in their present form before 1965, and, for comparisons involving the transition from late-model piston aircraft to early-model jet aircraft, only a single observation (in some cases taken from previous research monographs on the industry) is available. The second limitation occurs when only a short time interval is available between the introduction of a new model and the retirement of the corresponding old model. Since the Lockheed Electra (L188) was retired shortly after 1965, only one comparison is available between that aircraft and the Boeing 727-100 (the successor aircraft that typically replaced the Electra on medium-length routes). However, since the 727-100 has remained in service to this date, four comparisons of operating cost are available between the Boeing 727-100 and the "stretched" 727-200, in 1968, 1972, 1977, and 1982.[9] Whatever the limitations of this procedure, it seems to be the best available alternative and has the advantage that each pairwise comparison applies to a single year, thus holding constant output prices and the prices of operating inputs, particularly fuel and the wages of flight crews and maintenance labor.

The most important determinant of aircraft operating costs per seat mile at a given level of technology is "stage length" or "length of hop." A very short flight mainly consists of expensive takeoff and landing operations, with a slow average speed, whereas a long flight amortizes the takeoff and landing over a multihour flight segment at cruising speed. This fact dictates that the pairs of new and old models in the net revenue comparisons must be chosen to have roughly similar stage lengths in actual operation. Basic operating characteristics and cost data for successive generations of aircraft are presented in the three parts of table 4.8, that is, part A for long-range aircraft, part B for medium range, and part C for short range. Fifteen comparisons appear in the three sections of the table, involving eighteen different aircraft models. In size, the aircraft range from the small, two-engine piston short-range Convair 340/440, with forty-four seats, to the large wide-bodied long-range turbofan Boeing 747-100, with over 400 seats and capable of providing roughly twenty-five times the annual capacity. In chronological time, the aircraft models span the entire postwar period, beginning with the staple of early postwar air travel, the Douglas DC-6B, and continuing through the newest generation of jet aircraft, the Boeing 767-200 and the McDonnell-Douglas DC9-80 (now called the MD-80). The major types of aircraft that are excluded (to limit the time devoted to the analysis) are planes that are virtual duplicates of those analyzed here (e.g., the Boeing 707-100B, which is similar to the Douglas DC8-50), and a few planes that had short production runs (e.g., the Convair 880/990). There is also no coverage of aircraft used by commuter airlines.

The three sections of table 4.8 are arranged to present for each pair of models all the data used to calculate net revenue. Annual net revenue in

9. The limitation to comparisons at five-year intervals, rather than shorter intervals, was chosen to control the time devoted to this phase of the research.

Table 4.8 **Revenue and Operating Cost Data: Long, Medium, and Short Range**

Plane Types	Year	Revenue Hours per Year (1)	Air Speed (mph) (2)	Seats (3)	Annual asm (millions) (4)	Stage Length (5)	Load Factor (6)	Gross Revenue per rpm (7)	Net Revenue per asm (8)	Operating Cost per asm (9)	(7)-(8) (10)	Annual Net Revenue ($million) (11)
A. Long range:												
1. B767-200	1982	2,478	462	196.7	265.6	1,026	.667	.1254	.0435	.0310	.0125	3.328
L1011-100		2,894	471	287.7	388.4	1,038	.537	.1254	.0435	.0325	.0110	4.272
2. A300-B2	1982	2,823	450	241.0	317.2	908	.562	.1274	.0400	.0311	.0089	2.823
L1011-100		2,894	471	287.7	378.7	1,038	.537	.1274	.0400	.0339	.0061	1.755
3. L1011-100	1982	2,894	471	287.7	351.4	1,038	.537	.1279	.0403	.0328	.0075	2.636
DC8-61		2,473	444	199.5	244.9	860	.559	.1279	.0403	.0378	.0025	0.612
	1977	2,750	475	250.5	324.4	969	.515	.0896	.0274	.0195	.0088	2.855
		2,832	453	193.5	250.6	858	.548	.0896	.0274	.0195	.0079	1.980
	1972	2,356	489	213.7	305.3	1,237	.483	.0648	.0179	.0114	.0065	1.984
		3,001	463	175.0	250.0	942	.477	.0648	.0179	.0093	.0083	2.150
4. DC10-10	1982	2,963	491	264.8	336.5	1,453	.617	.1231	.0416	.0321	.0095	3.196
DC8-61		2,473	444	199.5	253.5	860	.559	.1231	.0416	.0378	.0038	0.963
	1977	3,174	487	244.2	344.7	1,283	.583	.0861	.0294	.0163	.0131	4.510
		2,832	453	193.5	273.1	858	.605	.0861	.0294	.0195	.0099	2.704
	1972	2,834	483	224.6	318.8	1,067	.452	.0658	.0176	.0082	.0094	3.000
		3,001	463	175.0	248.4	942	.477	.0658	.0176	.0093	.0083	2.062
5. B747-100	1982	3,344	508	405.6	647.0	2,101	.682	.1157	.0423	.0296	.0127	8.210
B707-300B		. . .	446	154.5	246.4	793	.589	.1157	.0423	.0445	−.0022	−0.541
	1977	3,436	503	374.3	561.5	1,794	.620	.0808	.0283	.0162	.0121	6.794
		2,802	459	154.4	231.6	1,026	.597	.0808	.0283	.0224	.0059	1.367
	1972	3,147	507	317.1	519.1	1,962	.458	.0576	.0162	.0085	.0077	3.997
		3,454	485	143.0	234.1	1,429	.528	.0576	.0162	.0103	.0059	1.381

6. DC8-61	1977	2,832	453	193.5	250.4	858	.548	.0895	.0289	.0195	.0094	2.063
DC8-50		. . .	461	133.8	173.2	946	.574	.0895	.0289	.0270	.0019	0.288
	1972	3,398	463	175.0	256.4	867	.477	.0626	.0193	.0095	.0098	2.513
		2,937	462	128.9	188.8	847	.515	.0676	.0193	.0121	.0072	1.359
	1968	3,633	470	196.6	342.1	1,094	.450	.0582	.0160	.0068	.0092	3.147
		3,749	473	134.1	233.4	910	.510	.0582	.0160	.0096	.0064	1.494
7. DC8-50	1965	3,699	479	125.5	222.4[c]	841	.523	.0668	.0211	.0113[e]	.0098	2.180
DC-7		. . .	286[a]	77.0	81.5[c]	750[d]	.585	.0668	.0211	.0198[e]	.0013	0.106
B. Medium range:												
8. DC9-80	1982	3,179	441	147.0	191.7	701	.530	.1345	.0426	.0252	.0174	3.336
B727-200		2,789	434	143.7	187.4	639	.575	.1345	.0426	.0368	.0058	1.087
9. B727-200	1982	2,789	434	143.7	157.8	639	.575	.1371	.0460	.0376	.0084	1.326
B727-100		2,248	438	109.0	119.7	666	.594	.1371	.0460	.0478	−.0018	−0.215
	1977	2,935	424	132.0	155.6	506	.565	.1047	.0353	.0221	.0132	2.054
		2,580	431	99.4	117.2	571	.608	.1047	.0353	.0296	.0057	0.068
	1972	2,613	427	123.3	136.0	550	.530	.0778	.0238	.0117	.0121	1.641
		2,519	433	96.2	106.1	542	.537	.0778	.0238	.0150	.0088	0.934
	1968	2,909	433	128.6	159.0	545	.474	.0702	.0212	.0076	.0136	2.162
		2,829	429	95.7	118.3	492	.579	.0702	.0212	.0129	.0083	0.982
10. B727-100	1965	2,518	389	94.1	92.8[c]	510	.612	.0775	.0266	.0123[e]	.0143	1.327
L-188		2,550	297	79.6	59.9[c]	500[d]	.589	.0775	.0266	.0143[e]	.0123	0.737
11. B-720B	1965	3,221	468	113.0	152.6[c]	698	.553	.0775	.0253	.0132[e]	.0123	1.846
L-188		2,550	297[a]	79.6	68.2[c]	500[d]	.589	.0775	.0253	.0143[e]	.0110	0.750
12. L-188	1965	2,550	297[a]	79.6	60.3[c]	500[d]	.589	.0775	.0253	.0143[e]	.0110	0.663
DC-6B		. . .	225[a]	69.5	39.9[c]	500[d]	.513	.0775	.0253	.0203[e]	.0050	0.197

(Continued)

Table 4.8 (continued)

Plane Types	Year	Revenue Hours per Year (1)	Air Speed (mph) (2)	Seats (3)	Annual asm (millions) (4)	Stage Length (5)	Load Factor (6)	Gross Revenue per rpm (7)	Net Revenue per asm (8)	Operating Cost per asm (9)	(7)-(8) (10)	Annual Net Revenue ($million) (11)
C. Short range:												
13. DC9-50	1982	2,655	390	124.5	124.9	367	.558	.1704	.0550	.0314	.0169	2.948
DC9-30		2,516	386	100.5	100.8	371	.571	.1704	.0550	.0396	.0154	1.552
	1977	2,694	375	114.9	118.5	387	.560	.1187	.0398	.0139	.0259	3.069
		2,763	381	91.4	94.3	348	.611	.1187	.0398	.0219	.0179	1.688
14. DC9-30	1982	2,516	386	100.5	94.1	371	.571	.1747	.0575	.0396	.0179	1.684
DC9-10		2,375	380	83.5	78.2	297	.579	.1747	.0575	.0448	.0127	0.993
	1977	2,763	381	91.4	88.5	348	.611	.1161	.0415	.0219	.0196	1.735
		2,362	397	70.3	68.1	435	.640	.1161	.0415	.0291	.0124	0.844
	1972	2,927	382	89.4	92.0	331	.595	.0916	.0311	.0113	.0198	1.822
		2,449	384	66.7	68.7	312	.594	.0916	.0311	.0152	.0159	1.092
	1968	2,373	360	90.1	81.8	283	.605	.0832	.0281	.0098	.0183	1.497
		2,533	379	69.9	63.4	287	.575	.0832	.0281	.0118	.0163	1.035
15. DC9-10	1965	2,789	389	66.6	77.3[c]	299	.716	.0803	.0294	.0148	.0146	1.128
CV340-440		. . .	211[a]	43.6	21.3[c]	250[d]	.570	.0803	.0294	.0243	.0051	0.109

Sources by column: (In the following notes,AOCPR refers to U.S. CAB, *Aircraft Operating Cost and Performance Report,* issued annually, 1965–84.) (**1**) Revenue hours per year, from AOCPR for the year in question. Blanks indicate that no figures are shown for piston planes, which are allocated the same yearly utilization as the first plane listed in each comparison. Also, the extremely low utilization of the B707-300B in 1982 and DC8-50 in 1977 is ignored, and the utilization of the comparison aircraft is used instead in those years. (**2**) Air speed is from AOCPR, except for comparisons noted by [a], which are from Douglas and Miller (1974), where block speeds shown are converted to air speed using the air/block ratio for the first plane listed in each comparison. (**3**) Average available seats per aircraft mile from AOCPR. (**4**) Annual available seat miles equals col. 3 times the average for each pair of models of revenue hours from col. 1 times the average for the two models in each comparison of air speed from col. 2. For comparison marked with [c], involving comparisons of jets with turboprops or piston planes, the calculation of annual available seat miles uses air speeds in col. 2 for each separate aircraft, rather than the average of the two. (**5**) Stage length is taken from AOCPR, except for comparisons marked with [d],where operating cost comparisons for both planes in the pair are taken from Strazheim (1969, 74) for the stage length indicated. (**6**) Load factors are from AOCPR for the year shown. (**7**) Gross revenue per revenue passenger miles is taken from a yield curve for 1971 adjusted for discounts, as displayed in Douglas and Miller (1974, 90). Points on the curve not shown in the Douglas-Miller table are interpolated linearly. The resulting yield is converted from a 1971 basis to the yield for each comparison year by using a conversion factor equal to the ratio of average passenger yield in that year to average passenger yield for 1971, from Bailey, Graham, and Kaplan (1985, app. A). (**8**) Net revenue per available seat mile is obtained by multiplying gross revenue per revenue passenger mile in col. 7 by two ratios. The first is the average load factor for the two planes in each comparison, from col. 6. The second is the ratio of aircraft operating costs plus flight equipment maintenance plus depreciation plus interest to total gross revenue minus imputed profit, 57.2 percent for the twelve months ending 30 June 1981, from Bailey, Graham, and Kaplan (1985, table 3.3, p. 136). (**9**) Flying operations costs plus flight equipment maintenance per available seat mile are from AOCPR, and are calculated by dividing average cost per block hour by seating capacity times block speed. The average speed for the two aircraft in a pair is used to adjust for the tilt of the cost curve. Average cost figures denoted by [e] are taken from Straszheim (1969, 74, 86), which refers to 1965. Straszheim's average cost figures refer to the stage length denoted by [d] in col. 5 and are adjusted to deduct depreciation in order to make them comparable to the other entries in this column. (**10**) Equals col. 7 minus col. 8. (**11**) Equals col. 10 times col. 4.

millions of dollars is shown in the right-hand column 11, and the ingredients in arriving at that figure are shown in the other columns. The stages in the calculation are as follows.

1. Annual available seat miles, that is, total output per year, is calculated as the product of hours per year, times air speed, times the number of seats. For jet aircraft, hours per year is the actual time flown, but, for piston aircraft by the 1960s, hours per year were very low—far below the actual time flown in the prejet era, and so the annual hours for the comparison aircraft are used instead. Since piston aircraft, even in their heyday, had more frequent maintenance downtime, this procedure overstates the annual output of piston aircraft. This error is one of several, including the decision to ignore the value of time savings and greater comfort, that make the final index understate the quality improvement involved in the transition from piston to jet aircraft. Since jet aircraft generally fly at the same speed on a given route, annual capacity (col. 4) is calculated by taking the average speed of the two jet aircraft shown. For comparisons involving piston aircraft, speeds are taken from a source that displays speeds for different aircraft types at given stage lengths. As for seating capacity, this is taken as the actual figure in different years. Note that the seating capacity of jet aircraft has generally increased since the early 1970s, reflecting a marketing decision to reduce the space devoted to the first-class cabin, the development of thinner seats, the development of overhead baggage racks that allow passengers to occupy less space without a proportional loss of comfort, and new engines that have increased the range and passenger-carrying capacity of aircraft carrying an unchanged model number. Effects of changing seating configurations are examined in table 4.11 below.

2. Gross revenue per revenue passenger mile, or passenger "yield," is *not* based on published fares, which overstate the increase in fares over the years by neglecting discounts. Instead, the yield calculation begins with a yield curve adjusted for discounts from Douglas and Miller (1974). Then the yield for a particular stage length for years before and after 1971 is calculated by taking the point on that curve and multiplying it by the change in average passenger yield (this takes account both of discounts and of the changing mix between first class and coach) between 1971 and the year of the model comparison.

3. The definition of load factor (lf) is revenue passenger miles (rpm) divided by available seat miles (asm) (lf = rpm/asm). Since operating costs are collected on an asm basis, it is necessary to convert yield per rpm (col. 7) to yield per asm. Another adjustment is to subtract from gross revenue that fraction that must be set aside to cover airline operating costs other than direct costs of flying operations. Gross revenue is converted to a net basis by a multiplicative factor equal to the ratio of aircraft operating costs, including flight equipment maintenance plus depreciation and interest, to total gross revenue minus imputed profit, from the recent study by Bailey, Graham, and

Kaplan (1985). The resulting figure, expressed in column 8 on a basis per asm, is the amount available to cover costs of flying operations and maintenance shown in column 9. The difference, shown on an asm basis in column 10 and on a per-annum basis in column 11, is then available to cover depreciation and interest, with any residual contributing to operating profit.

The resulting estimates of net revenue display a fairly consistent pattern. In those comparisons, in which net revenue estimates are available for several successive five-year intervals, note that the relative advantage of the newer model in generating net revenue seems to increase as time goes on. For instance, the net revenue per asm of the 747-100 is only slightly above that of the 707-300 in 1972, but by 1982 the figure for the 747-100 has increased while that for the 707-300 has become negative. Similarly, the 1982 estimate for the 727-100 is negative. Thus, it is not surprising that by 1982 most U.S. airlines had grounded and/or retired their fleets of 707 aircraft and were operating 727-100 aircraft at relatively low utilization rates. Overall, it appears that the DC-9 series of short-haul aircraft produces the highest net revenue per asm, but total annual net revenue is highest for the Boeing 747-100, owing to its large annual capacity of asms.

Table 4.9 combines these net revenue estimates with data on the sales prices of various plane types. The prices are the same as those used in table 4.2 to compute the price indexes for identical models. In most cases, the "old" and "new" models being compared were not actually constructed simultaneously, requiring the adjustment of the price of the old model for changes in the price of identical models (using the interpolated SMSA index) between the year of its disappearance and the first sales year of the new model. In this way, the sales prices of the two planes in each comparison are computed for the same year, allowing the price of output and operating inputs to be held constant. For instance, in part A of table 4.9, there was no overlap in the construction dates of the L-1011 and DC8-61. The comparison for 1972 uses the average sales price for that year for the airlines purchasing the L-1011, from the data base used in developing tables 4.2 and 4.4 above. The price for the DC8-61 is the average 1968 price from the same data base, times the 1972/1968 ratio of the interpolated SMSA index in table 4.3. The 1977 and 1982 comparisons exhibit the implied prices when the 1972 price comparison is adjusted for the change in the interpolated SMSA index after 1972.

Each table is arranged with the comparisons of the most recent models at the top of each of the three sections (for long range, medium range, and short range), while at the bottom are displayed the comparisons for the transition between piston and jet aircraft. Column 4 shows the ratio of annual net revenue to the implied replacement price and indicates the enormous profitability of jet planes, compared to the piston planes they replaced. Because most airlines depreciated their piston planes over seven- or eight-year intervals, it is apparent that the DC-7 in part A of table 4.9 must have have

Table 4.9 **Calculation of Price Change: Long, Medium, and Short Range**

Plane Types	Year	Original Price (Year) (1)		Price in Comparison Year (2)	Net Revenue in Comparison Year (3)	n_t/v_t (4)	v_{1t}/v_{0t} (5)	n_{1t}/n_{0t} (6)	(5)/(6) -1 (7)	(7) With Curvature Adjustment (8)
A. Long range:										
1. B767-200	1982	33.9	(1983)	33.0	3.328	0.101	1.003	0.779	0.288	0.354
L1011-100		33.8	(1983)	32.9	4.272	0.130				
2. A300-B2	1982	22.7	(1981)	25.2	2.823	0.112	0.778	1.609	−0.516	−0.560
L1011-100		29.1	(1981)	32.4	1.755	0.054				
3. L1011-100	1982	15.4	(1972)	33.5	2.636	0.077	1.840	4.307	−0.573	−0.681
DC8-61		7.5	(1968)	18.2	0.612	0.033				
	1977			21.5	2.855	0.129	1.840	1.442	0.276	0.185
				11.7	1.980	0.169				
	1972			15.4	1.984	0.129	1.840	0.923	0.933	1.026
				8.4	2.150	0.256				
4. DC10-10	1982	15.3	(1972)	33.2	3.196	0.093	1.820	3.319	−0.452	−0.569
DC8-61		7.5	(1968)	18.2	0.963	0.053				
	1977			21.3	4.510	0.212	1.820	1.486	0.225	0.131
				11.7	2.704	0.231				
	1972			15.3	3.000	0.196	1.820	1.455	0.251	0.160
				8.4	2.062	0.245				
5. B747-100	1982	21.2	(1972)	46.1	8.210	0.130	2.986	. . .	. . .	. . .
B707-300B		6.2	(1966)	15.5	−0.541	−0.026				
	1977			29.5	6.794	0.223	2.986	4.970	−0.399	−0.564
				9.9	1.367	0.138				
	1972			21.2	3.997	0.189	2.986	2.894	0.032	−0.166
				7.1	1.381	0.175				

(continued)

Table 4.9 (continued)

Plane Types	Year	Original Price (Year) (1)		Price in Comparison Year (2)	Net Revenue in Comparison Year (3)	n_t/v_t (4)	v_{1t}/v_{0t} (5)	n_{1t}/n_{0t} (6)	(5)/(6) -1 (7)	(7) With Curvature Adjustment (8)
6. DC8-61	1977	7.5	(1968)	11.7	2.063	0.176	1.316	7.163	−0.816	−0.876
DC8-50		5.5	(1966)	8.8	0.288	0.033				
	1972			8.4	2.513	0.299	1.316	1.849	−0.288	−0.370
				6.3	1.359	0.216				
	1968			7.5	3.147	0.420	1.316	2.106	−0.375	−0.461
				5.7	1.494	0.262				
7. DC8-50	1965	4.4	(1959)	4.8	2.180	0.422	2.670	20.573	−0.873	−0.929
DC-7		1.6	(1958)	1.8	0.106	0.059				
B. Medium range:										
8. DC9-80	1982	22.4	(1983)	21.8	3.336	0.153	1.703	3.069	−0.445	−0.557
B727-200		9.5	(1979)	12.8	1.087	0.085				
9. B727-200	1982	5.3	(1969)	12.5	1.326	0.106	1.147	. . .	. . .	. . .
B727-100		4.6	(1969)	10.9	−0.215	−0.020				
	1977			8.6	2.054	0.257	1.147	3.075	−0.627	−0.702
				7.0	0.668	0.095				
	1972			5.8	1.646	0.283	1.147	1.762	−0.349	−0.418
				5.0	0.934	0.187				
	1968			5.2	2.162	0.416	1.147	2.202	−0.479	−0.555
				4.5	0.982	0.218				
10. B727-100	1965	3.9	(1963)	4.1	1.327	0.324	2.158	1.801	0.198	0.065
L-188		1.7	(1959)	1.9	0.737	0.388				
11. B-720B	1965	3.7	(1961)	4.0	1.846	0.462	2.105	2.461	−0.145	−0.286
L-188		1.7	(1959)	1.9	0.750	0.395				
12. L-188	1965	1.7	(1959)	1.9	0.663	0.326	1.727	3.374	−0.488	−0.599
DC-6B		1.0	(1958)	1.1	0.197	0.156				

C. Short range:										
13. DC9-50	1982	5.6	(1978)	8.0	2.948	0.369	1.038	1.900	−0.453	−0.519
DC9-30		3.1	(1967)	7.7	1.552	0.202				
	1977			5.1	3.069	0.602	1.038	1.818	−0.429	−0.493
				5.0	1.688	0.338				
14. DC9-30	1982	3.1	(1967)	7.7	1.684	0.259	1.100	1.696	−0.352	−0.417
DC9-10		2.8	(1966)	7.0	0.993	0.070				
	1977			4.9	1.735	0.354	1.100	2.056	−0.464	−0.536
				4.5	0.844	0.188				
	1972			3.5	1.822	0.521	1.100	1.668	−0.340	−0.405
				3.2	1.092	0.341				
	1967			3.1	1.497	0.483	1.100	1.449	−0.241	−0.291
				2.8	1.033	0.369				
15. DC9-10	1965	2.8	(1966)	2.8	1.128	0.403	4.000	10.349	−0.613	−0.758
CV340/440		0.6	(1957)	0.7	0.109	0.156				

Sources by column: (1) All price data are for airframes, excluding engines, from CAB Form 41, Schedule B-43. Table 4.7 shows the average price paid by the following airlines, with the year of the schedule B-43 shown in parentheses for all comparisons but the first. *Long range:* (1) Schedule B-7, price paid by Delta for both the 767 and the L-1011 in the quarter ending 6-30-83; (2) A-300, Eastern, price paid in 1981 (12-31-82); L-1011, Delta, price paid in 1981 (12-31-82); (3) L-1011, average price paid by Eastern and TWA in 1972 (12-31-73); DC8-61, average price paid by Delta and United in 1968 (12-31-73); (4) DC10-10, average price paid by American and United in 1972 (12-31-73); DC8-61, same as comparison 3; (5) B747-100, average price paid by United in 1972 (12-31-73); B707-300B, average price paid by TWA in 1966 (12-31-67); (6) DC8-61, same as comparison 3; DC8-50, average price paid by Delta and United in 1966 (12-31-67); (7) DC8-50, same as comparison 6; DC-7, average price paid by United in 1958 (12-31-61). *Medium range:* (1) DC9-80, average price paid by PSA in the quarter ending 6-30-83, from schedule B-7; B727-200, average price paid by American, TWA, and United in 1969 (12-31-73); (2) B727-200, average price paid by American, TWA, and United in 1969 (12-31-73); B727-100, average price paid by TWA in 1969 (12-31-73); (3) B727-100, average price paid by United in 1963 (12-31-67); L-188, average price paid by American in 1959 (12-31-67); (4) B-720B, average price paid by American, Braniff, and United in 1961 (12-31-61); DC-6B, average price paid by United in 1958 (12-31-61); (5) L-188, same as comparison 3; DC-6B, same as comparison 4. *Short range:* (1) DC9-50, average price paid by Eastern in 1978 (12-31-78); DC9-30, average price paid by Delta and Eastern in 1967 (12-31-67); (2) DC9-30, same as comparison 1; DC9-10, average price paid by TWA in 1966 (12-31-67); (3) DC9-10, same as comparison 2; CV-440, average price paid by Delta and Eastern in 1957 (12-31-61). (2) Price in comparison year is the price shown in col. 1, multiplied by the ratio of the interpolated SMSA price index for identical models in the comparison year relative to the year shown in col. 1, from table 4.4, col. 2. (3) Table 4.4, col. 11. (4) Ratio of col. 3 to col. 2. (5) Ratio of col. 2 for first-listed model to second-listed model. (6) Ratio of col. 3 for first-listed model to second-listed model. (7) Ratio of col. 5 to col. 6, minus 1.0. (8) Ratio of col. 5 to col. 6, times col. 6 raised to the −0.2 power, minus 1.0.

been operated at a loss, with an n/v ratio of just 0.027, while the DC-6B and Convair 340/440 exhibit n/v ratios of 0.156 each, just sufficient to pay depreciation without leaving anything left over for profit. The most profitable aircraft appear to have been the DC8-61 in 1968, the 727-200 in 1968, and the DC9-50 in 1977, with respective n/v ratios of 0.420, 0.416, and 0.478. These ratios may seem unreasonably high, and one reason for this is that the aircraft prices shown in table 4.9 exclude engines, implying a total price about 25 percent higher than shown in column 1 and an n/v ratio about 20 percent lower than that shown in column 4. As long as there has been no significant drift over time in the ratio of engine prices to airframe prices, the omission of engine prices should not influence the remaining results discussed below.

Seven of the fifteen model comparisons in table 4.9 provide net revenue data that cover more than one year. This allows us to examine the pattern of change in the net revenue of new relative to old models as the new models ''age'' following their year of introduction. To the extent that new models are larger than old models and allow a reduction in labor cost and fuel cost per passenger, we should expect to find that the relative profitability of new models declines less rapidly than that of old models over time as fuel and labor costs rise. And we should expect a discontinuity after the two oil shocks of 1973–74 and 1979–80, since these were events that caused quantum jumps in the price of airline fuel and should have resulted in substantial declines in the profitability of older, less fuel-efficient models compared to new models.

The seven model comparisons in table 4.9 that cover more than one year are based on identical ratios of sales prices (v_1/v_0), but ratios of net revenue (n_1/n_0) that reflect the differing operating conditions of each year. Since the relative price changes displayed in column 7 depend only on these two ratios, they provide a concise summary of changes in profitability over time. The expected decline over time in the profitability of the old model relative to the new model should be reflected in relative price changes in column 7 that shift in a negative direction (either from positive to negative or from negative to more negative).This presumption of a negative shift in the price changes displayed in column 7 is confirmed by each of the seven multiyear model comparisons. Consider, for example, the four multiyear model comparisons displayed for long-range aircraft in part A of table 4.9. The first three of these (L-1011 vs. DC8-61; DC10-10 vs. DC8-61; and B747-100 vs. B707-300B) indicate a relative price *increase* in the year of introduction, but by 1982 a substantial relative price *decrease*. In the fourth comparison, a price decrease of 37.5 percent in 1968 becomes a decrease of 81.6 percent in 1977, as shown in column 7.

While increasing fuel and labor costs were mainly responsible for making older models uneconomical in the 1972–82 period, an additional factor was a change in marketing philosophy. Originally, the new larger aircraft, especially

Table 4.10 **Number of Seats, Seat Widths, and Pitch for United Airlines, for Various Models of Jet Aircraft**

	Total Number of Seats	Seat Width (inches)[a]	Pitch (inches)[a]
Boeing 747	429	17	34
Douglas DC-10	254	17	36
Boeing 767	197	18	34
Douglas DC8-71	191	17	36
Boeing 727-200	147	17	32
Boeing 727-100	108	17	34
Boeing 737-200	109	17	32

Sources: Seating capacity and dimensions from *Great Seats in the Friendly Skies,* brochure, United Airlines, July 1983.

[a]Seat widths and pitch are just for the economy cabin, but the first-class cabin generally contains 10 percent or less of the total seats

the wide-bodied 747, DC-10, and L-1011, were introduced with wider seats and greater "pitch" (i.e., distance between seats) than the narrow-bodied models that they replaced. It is impossible to place a quantitative value on the benefit that passengers received in the early years of the wide-bodied aircraft, since there was no fare differential to test the passengers' willingness to pay for comfort. However, as rising fuel prices created tough times for the airline industry, marketing executives recognized an opportunity to equalize the seating density of wide-bodied and narrow-bodied aircraft. Thus, note in part A of table 4.8 that average seats in the 747 increased between 1972 and 1982 from 317 to 406, in the DC-10 from 225 to 265, and in the L-1011 from 214 to 288.

The presumption is that this shift made the comfort of a wide-bodied aircraft equivalent to that of a narrow-bodied aircraft like the DC8-61 or B707-300, rather than inferior to that of a narrow-bodied aircraft. This is supported by evidence that the seating configurations that have been typical in recent years provide comparable seating width and pitch in older and newer models of jet aircraft. Corroborative figures are available for United Airlines, given in table 4.10. Since seat width is virtually the same, differences in passenger comfort could be attributed only to pitch. However, these figures for seat pitch do not suggest any substantial revision in the net revenue calculations in table 4.8 for 1982, and they *do* suggest that the net revenue of wide-bodied aircraft in their early years (e.g., 1972) was understated due to the temporary provision to the passenger of extra comfort.[10]

10. For instance, that 1982 ratio for the comparison of the DC10-10 with the DC8-61 indicates a seating ratio of 1.327. The ratio for the United configuration displayed in the text is 1.330, almost the same, and these two aircraft as flown by United offer passengers the same seating pitch (the airframe of the DC8-71 is identical to that of the DC8-61, since the two models differ only in the quieter, more fuel-efficient engines installed on the DC8-71). The tighter pitch of the 727-200 than the 727-100 in the United configuration might call for a

The final column in table 4.9 provides an estimate of the relative price change that takes account of the curvature of the function that links the relative price of new models to their relative capacity of earning net revenue. There appears to be no direct way of estimating this function by examining the cross section of planes built at any given time, because the planes built in the long-range, medium-range, and short-range categories are really separate products that defy comparisons. Further, at any given time, only the most advanced plane in each category is constructed. In lieu of any direct evidence on the curvature of the function by which aircraft manufacturers translate extra cost into extra ability to generate net revenue, the curvature parameter used in the calculations in column 8 of table 4.9 has been assigned a value of 1.2, implying diminishing returns, with an elasticity of net revenue to increases in manufacturing cost of $1/1.2 = 0.833$. If an increase in net revenue can be achieved with constant returns in manufacturing cost, then the relative price changes exhibited in column 7 are relevant, whereas a greater degree of diminishing returns would imply the need for a greater curvature adjustment than that shown in column 8.

As noted above, some of the relative price comparisons in table 4.9 are influenced by changes in seating configurations over time; wide-bodied aircraft introduced in the early 1970s initially offered passengers the comfort of wider seats than on narrow-bodied aircraft, but gradually these seats were replaced by the standard seats with which other jet aircraft were equipped. At least part of the relatively low profitability of wide-bodied aircraft in table 4.9 in 1972 can be explained by low seating capacities. To investigate the importance of this point, table 4.11 repeats the curvature-adjusted price changes from column 8 of table 4.9 and compares these with equivalent price changes recalculated to hold constant the seating capacity of aircraft (the base year is the most recent year shown in table 4.11, designated by an asterisk). For instance, the first pair of models shown, the L1011-100 and DC8-61, exhibit a relative price *increase* of 102.6 percent in the introductory year of 1972, but when net revenue for both aircraft is recalculated with 1982 seating capacities(which raises annual capacity and reduces operating cost per unit of capacity), the relative price increase is a much smaller 22.8 percent. The average relative price *decline* in the comparisons displayed in table 4.11 is 22.3 percent with actual seating capacities and 28.0 percent with standard base-year seating capacities.

The relative price changes with standardized seating configurations exhibit a consistent pattern in almost all the model comparisons. There is little

"comfort adjustment." But this would be minor: the seating capacity ratio in pt. B of table 4.8 for 1982 is 1.319, and the United ratio for 1983 with the differing comfort is 1.361. Assuming that a thirty-four-inch pitch for the coach cabin of the United 727-200 would reduce seating capacity from 147 to 139, for a seating capacity ratio for the 727-200 vs. the 727-100 of 1.287. This would reduce the annual net revenue figure for the 727-200 given in pt. B of table 4.8 by only 2.4 percent, not enough to create any appreciable change in the results.

Table 4.11 **Relative Price Changes Calculated with and without Standard 1982 Seating Configuration (includes curvature adjustment)**

Models in Pair	Year	Actual Configuration (1)	Standard Base-Year Configuration (2)
L1011-100	1982*	−0.681	−0.681
DC8-61	1977	0.185	−0.076
	1972	1.026	0.228
DC10-10	1982*	−0.569	−0.569
DC8-61	1977	0.131	−0.112
	1972	0.160	0.123
B747-100	1982*	. . .	. . .
B707-300B	1977	−0.564	−0.647
	1972	−0.166	−0.391
DC8-61	1977*	−0.876	−0.876
DC8-50	1972	−0.370	−0.436
	1968	−0.461	−0.447
B727-200	1982*	. . .	. . .
B727-100	1977	−0.702	−0.592
	1972	−0.555	−0.447
DC9-30	1982*	−0.417	−0.417
DC9-10	1977	−0.536	−0.338
	1972	−0.405	−0.213
	1967	−0.291	−0.180
Average for years Other than Base Year		−0.213	−0.280

Source: Tables 4.8 and 4.9; method explained in text.
*Base year.

difference in the relative price changes recorded for 1967–68 and 1972, but then the relative price change shifts in a negative direction between 1972 and 1977 and again between 1977 and 1982. The pattern reflects the influence of the 1973–74 and 1979–80 oil shocks, which had a greater impact in reducing the estimated net revenue of older models, and hence increasing the estimated relative price decline between the old and new models, due to the higher fuel consumption per seat mile of older models. (The two comparisons designated by ellipses points for 1982 are consistent with a greater advantage of newer models than in 1977, i.e., a greater relative price decline, but in these cases the net revenue of the older model has become negative, preventing the calculation of the extent of the relative price decline.)

4.6 Used Aircraft Prices and Pairwise Model Quality Comparisons

All the pairwise model relative price changes developed in the last section were based on constructed estimates of net revenue. However, the "true" value of one aircraft model compared to another is established in the marketplace for used assets. While many categories of capital goods are either "bolted down" or require high moving costs to be sold, commercial aircraft are among the most mobile of capital goods, and are bought and sold constantly on an active market for used aircraft. It has been estimated that the value of used aircraft transactions involving U.S. airlines has cumulated to $4.5 billion over the 1970–83 period (Avmark 1984). Since it is possible to obtain price quotes or estimates from the used aircraft market for most of the models involved in the comparisons of tables 4.8, 4.9, and 4.11, we can test the implication of the theoretical analysis in chapter 2. There was derived the condition that used asset prices of different models observed at a given moment should be observed to be proportional to their respective ability to earn net revenue. Repeating equation (2.38), we have:

$$\frac{A_{1t}}{A_{0t}} = \frac{N_{1t}}{N_{0t}}, \tag{4.7}$$

where A is the price of the used asset at a given time, and N is net revenue for the same model. In this light, we can view the investigation of used aircraft prices as a test of the validity of the estimates of net revenue (N) contained in the last section. An important reason why the valuation of two models in the marketplace may differ from the net revenue estimates is a different depreciation rate on model 1 and model 2, in contrast to the assumption of identical depreciation rates in the derivation of (4.7) and of the net revenue ratios in table 4.8. For instance, the marketplace knew in 1982 that the DC8-61 aircraft would become obsolete in 1985 under then-announced federal antinoise regulations, and this model is valued less by the used aircraft market than would be implied by our net revenue estimates.[11]

Table 4.12 displays used price quotations for the same years that were chosen above for the pairwise model net revenue comparisons (no quotations for 1967–68 are available). Every model that appears in the net revenue comparisons is also listed here, with the single exception of the recently introduced Boeing 767. Figures enclosed in parentheses indicate actual price quotations (asking prices for 1965, transaction prices for other years), while other figures are estimates made by the *Avmark Newsletter,* a trade publication that covers activity in the used aircraft market. It is evident from table 4.12 that there is a high correlation between price quotations and estimates when both are available for the same model and the same year, and that discrepancies are mainly in the direction of Avmark underestimating the value of newer models, for example, the advanced Boeing 727-200 and the DC9-50. The advantage of including the Avmark estimates is that they provide figures for 1977 and 1982 covering several planes for which no

11. The residual value of the DC8-61 in 1982 was for its conversion potential. It was economically feasible to attach new modern engines to this aircraft model, which was then rechristened the DC8-71. Such conversions were not economical for the nonstretched B-707 and nonstretched DC8-50 models, and so their prices by 1982 had fallen close to scrap value.

Table 4.12 **Prices of Used Commercial Aircraft, Various Years, by Model (in $million)**

	1965 (1)	1972 (2)	1977 (3)	1982 (4)
Long range:				
1. A300-B2	...	...	19.0	22.5
2. L1011-100	...	...	22.3	19.0
3. D10-10	...	...	21.5	18.0
4. B747-100	...	...	24.0	22.5
5. DC8-61	...	(6.7)	6.3 (6.0)	3.0
6. DC8-50	...	(2.3)	1.4 (1.7)	0.5
7. B707-300B	...	(3.3)	4.0 (3.8)	0.8 (1.3)
8. DC-7	(0.25)	...	...	...
Medium range:				
9. DC9-80	...	...	...	17.5
10. B727-200(ADV)[a]	...	...	...	6.8 (10.2)
11. B727-200	...	(5.0)	7.5	5.8 (5.3)
12. B727-100	...	(2.7)	2.9 (3.1)	2.0 (1.7)
13. B-720B	...	(1.5)	... (1.0)	...
14. L-188	(1.00)	...	... (0.4)	...
15. DC-6B	(0.35)	...	...	...
Short range:				
16. DC9-50	...	...	7.0 (9.2)[b]	9.5 (10.7)[c]
17. DC9-30	...	(3.8)	4.3 (4.2)	5.3 (5.3)
18. DC9-10	...	(2.2)	2.2 (2.8)	2.5 (1.9)
19. CV-340	(0.30)	...	...	...

Note: All numbers in parentheses are actual price quotes, i.e., the average price paid for all aircraft of a given type sold in a given year. Sources for price quotes by year are: 1965: *Aircraft Exchange and Services Newsletter*, no. 130, 8 January 1965 (prices shown are asking prices); 1972,1977, 1982: prices actually paid are read off charts published in the *Avmark Newsletter*, various dates. The charts cover the period 1970–82 and indicate for each year (1970–77) and each quarter (1978–82) the number of aircraft of a given type sold and the average price received. The charts used and dates of publication are as follows: DC8-50, DC8-61: March 1982, 16; Boeing 720B, 707-120B, 707-320B: March 1983, 16; DC9-10, DC9-30, DC9-50, Boeing 737-200: September 1983, 18; B727-100, B727-200, B727-200 (ADV): October 1983, 20; All numbers not in parentheses are estimates of current market value published semiannually in the *Avmark Newsletter*. Price quotes shown are from the July issue of 1977 and 1982.

[a]ADV stands for the "advanced" B727-200 model.

[b]Price quote refers to 1978 rather than 1977.

[c]Price quote refers to 1981 rather than 1982.

direct price quotations are available, and this allows the study to include virtually the full range of models for which net revenue estimates have been compiled. The fact that Avmark tends to underestimate the value of newer models implies that the use of Avmark estimates tends correspondingly to understate the quality and/or efficiency advantage of new models and the associated relative price decline.

Equation (4.7) suggests that, at a given moment of time in comparing a new model with an old model, the ratio of their used asset price should be equal to the ratio of their net revenue. Table 4.13 displays pairwise model comparisons of net revenue and used price ratios. In the columns labeled u_0/u_1, the numbers in parentheses indicate used price comparisons in which both the numerator and denominator are price quotations as opposed to price

Table 4.13 **Net Revenue and Used Price Ratios for "New" and "Old" Model Comparison Pairs**

	1965		1972		1977		1982	
Comparison	n_1/n_0 (1)	u_1/u_0 (2)	n_1/n_0 (3)	u_1/u_0 (4)	n_1/n_0 (5)	u_1/u_0 (6)	n_1/n_0 (7)	u_1/u_0 (8)
1. A-300/L-1011	...	...	...	...	...	0.85	1.61	1.18
2. L-1011/DC8-61	...	...	0.92	...	1.44	3.54	4.31	6.33
3. DC-10/DC8-61	...	...	1.46	...	1.49	3.58	3.32	6.00
4. B-747/B-707	...	...	2.89	...	4.97	6.00	...	28.13
5. DC8-61/DC8-50	...	...	1.85	(2.91)	7.16	4.50 (3.53)	...	6.00
6. DC8-50/DC-7	20.57	19.20*	...	...	...	...	...	...
7. DC9-80/B727-200	...	...	...	...	...	...	3.07	3.01
8. B727-200/B727-100	...	...	1.76	1.85	3.08	2.59	...	2.90 (3.11)
9. B727-100/L-188	1.80	4.10*	...	...	...	... (7.75)	...	...
10. B-720B/L-188	2.46	4.00*	...	...	...	... (2.50)	...	...
11. L-188/DC-6B	3.37	2.86	...	...	...	...	...	...
12. DC9-50/DC9-30	...	...	...	...	1.82	1.62	1.90	1.79 (2.00)
13. DC9-30/DC9-10	...	...	1.67	(1.72)	2.06	1.95 (1.50)	1.70	2.12 (2.79)
14. DC9-10/CV-340	10.35	9.33*	...	...	...	...	...	...

Sources by column: (**1, 3, 5**) Table 4.9, col. 6. (**2, 4, 6**) Table 4.12.

Note: Parentheses indicate that both components of the ratio are actual price quotations. An asterisk indicates that the price quotation for the newer model is the1965 price of a new aircraft. See text.

estimates, and numbers without parentheses indicate that both numerator and denominator are Avmark price estimates.[12] A count of table 4.13 indicates twenty-one cases in which a pairwise net revenue ratio can be compared with a used asset price ratio (when both price quotations and Avmark estimates are available, only the ratio based on the former is counted). The unweighted average of the twenty-one used asset price ratios is 4.26, considerably higher than the 3.89 average for the twenty-one corresponding net revenue ratios. Excluding the extreme values for the comparison of the DC8-50 and DC-7, with a used asset price ratio of 19.2 and a net revenue ratio of 20.57, the respective averages are 3.52 and 3.06. A cross-sectional regression of the twenty net revenue ratios (n) on the twenty used price ratios (u) yields the following:

$$(4.8) \qquad n = \underset{[0.15]}{0.105} + \underset{[4.98]}{0.839u}, \quad R^2 = 0.556, \; SEE = 1.49,$$

12. In comparisons for 1965 designated with an asterisk, no used price quotation is available for the newer model. In these cases, the price of the newer model is taken to be the price of that model sold new in 1965, from table 4.9. Recall that the data on new prices paid do not include engines, while the price quotations for used models do include engines. Assuming that engines contribute roughly 25 percent of the final total price of a new model, we implicitly treat the used price of a new model in 1965 as equal to 1.00/1.25 = 0.8 of the price of the corresponding newly produced aircraft. This approach is supported by a comment that appears in the *Avmark Newsletter* (July 1982, 2): "These prices are for the earlier models, with newer models approaching new aircraft prices in value."

where t-ratios are in brackets. There is a strong positive association between n and u, but the standard error of estimate is quite high.

Several speculations may be offered to explain the largest discrepancies between the n and the u ratios in table 4.13. In the first comparison, that between the B-767 and the L-1011, the net revenue technique registers a relative price *increase* of 35 percent, while the used price comparison registers a relative price *decrease* of 49 percent. This comparison should not be given much weight, since there is no used price observation available for the brand-new 767 in 1982, and I use the price of the new aircraft instead (see n. 13 below). Most of the 767 aircraft sold in 1982 and 1983 were to airlines that had placed orders in 1978–79 when expected fuel prices for 1982 were much higher than actual prices turned out to be. The relative price increase indicated by the net revenue calculation in column 3 suggests that the operating efficiency of the 767 did not compensate for its high purchase price at the actual fuel prices of 1982. Airlines that might have wanted to back out of this transaction may have been prevented from canceling orders by stiff cancellation penalties. The makeshift device of comparing the price of the new 767 with the price of a used L-1011 may appear to be responsible for the problem, but the same technique leads to a close correspondence of the net revenue ratio and the new/used price ratio in the 1965 comparisons of the DC8-50 and DC-7 and of the DC9-10 with the Convair 340/440.

The net revenue technique appears to value the DC8-61 significantly more highly than does the used aircraft market. This probably occurs because the net revenue approach treats the expected lifetime of all aircraft as identical in a given year, whereas the used aircraft market "knew" that federal antinoise regulations would make the DC8-61 obsolete in 1985 without expensive engine "retrofitting" (see n. 12 above). The net revenue technique also appears to undervalue the B727-100 and B720B relative to the Lockheed Electra (L-188), since the net revenue calculation is based strictly on profit potential and assumes that both new-model and old-model aircraft operate at the same load factor. This neglects the additional passenger comfort and time savings made possible by the B727-100 and other early-generation jet aircraft that made the L-188 obsolete less than ten years after its introduction in 1958–59.

The treatment of used aircraft prices incorporates a feature that may appear to be peculiar, and this is that depreciation is assumed to be purely economic, with no depreciation attributed to physical wear and tear or to the passage of time. Thus, prices of used aircraft are compared in tables 4.12 and 4.13 without regard to their age. This would seem to create a bias when the used price ratios are interpreted as measuring the relative quality of new and old models of a given age, since part of the higher used price paid for the newer model must surely include an allowance for depreciation. While plausible, this qualification is not likely to be of major importance. First, physical depreciation is much less important for aircraft than for automobiles and trucks, both because of virtually continuous maintenance and because of the absence of direct contact with corrosive materials like road salt. Second, in table 4.13, we have successive observations on the used aircraft price ratios of new and old models of roughly the same age—B727-100 and early B727-200 aircraft manufactured in, respectively, 1964–67 and 1967–70, and DC9-10 and DC9-30 aircraft manufactured only a few years apart, in 1966–68 and 1968–70. While the newer model in these pairs was substantially younger in 1972, by 1982 the newer model was only marginally younger (e.g., fourteen vs. seventeen years). Thus, if physical depreciation had been important, we should have expected the price differential between the newer and the older model to narrow, but in fact the differential was substantially wider for both cases, supporting the hypothesis that economic depreciation dominates physical depreciation. Another persuasive example of the importance of economic depreciation is the case of the piston DC-7, since aircraft of this type that were newly manufactured in 1958 were declared to be worth only scrap value just a year later.[13] Some of the most dramatic implied relative price declines between old and new models were those involving the first-generation long-range jets, for example, the DC8-50 and the B707-100, and these aircraft replaced final-generation piston aircraft that in many cases were only two or three years older.

4.7 Price Indexes Adjusted for Changes in Operating Efficiency

Overall, it appears from the used price comparisons that the measures of relative price change between old and new models based on net revenue data may be too conservative. But, by not allowing at all for physical depreciation, the measures of relative price change based on comparisons of used aircraft prices may be too liberal, and this section develops real and nominal price indexes based on both data sources. Table 4.14 summarizes the ingredients in the calculation. The various pairwise model comparisons are listed as before by stage length and are allocated to chronological "generations." Several aircraft of a given stage length are allocated to the same generation if they were manufactured simultaneously for a substantial length of time, as in the case of the B-747, L-1011, and DC-10, but to different generations if the manufacture of the older model was terminated on the introduction of the newer model or soon thereafter. The newer model of each comparison is indicated in column 1, and column 2 lists other similar models that are treated as being essentially identical for the purpose of assigning weights. Relative price changes between old and new models

13. Thus, a study completed in February 1959 predicted that, by the end of 1959, a brand-new DC-7 would be worth only scrap value (see Sobotka 1959, table 6, p. 18). Other models predicted to reach scrap value by 1961 include the DC-3, DC-6, and all models of the Lockheed Constellation (L-049, L-749, etc.).

Table 4.14 **Relative Price Changes and Weights Used in Calculating Quality-Adjusted Relative Price Index**

Generation Number and New Model (1)	Other Models Included (2)	Relative Price Change (Tables 4.6–4.7) (3)	Ratio of Used Aircraft Prices (4)	Relative Price Change from (4) (5)	Years of Transition and Weight (6)	
Long range:						
1. DC8-50	B707-100B B707-300B	−.929	19.20	−.923	1959–60	1.00
2. DC8-61	. . .	−.586	4.15	−.761	1967–68	0.35
3. L1011-100	. . .	−.126	4.94	−.729	1972–73	0.10
					1974–75	0.01
DC10-10	. . .	−.186	4.79	−.722	1971–72	0.22
					1974–75	0.02
B747-100	. . .	−.519	6.00[a]	−.652	1970–71	0.59
					1974–75	0.06
4. B767-200	B-757	.354	1.76	−.491	1982–83	0.50
A300-B2	. . .	−.560	1.01	−.236	1978–79	0.25
Medium range:						
1. L-188	. . .	−.599	2.86	−.511	1958–59	1.00
2. B727-100	CV880,990	.065	5.92	−.745	1964–65	0.70
B-720B	. . .	−.286	3.25	−.488	1961–62	0.30
3. B727-200	. . .	−.478	2.52	−.622	1967–68	1.00
4. DC9-80	. . .	−.557	3.01	−.546	1982–83	1.00
Short range:						
1. DC9-10	. . .	−.758	9.33	−.726	1966–67	1.00
2. DC9-30	B737-200	−.287	2.00	−.521	1968–69	1.00
3. DC9-50	. . .	−.506	1.81	−.491	1978–79	0.20

Sources by column: (**1**) Models shown are the "new models" chosen for the comparisons in tables 4.5 and 4.6. The "old models" in each comparison are those displayed in tables 4.5 and 4.6. (**2**) These models were treated as being essentially identical with the new models displayed in col. 1 for the purposes of establishing the weights for individual models shown in col. 6 and those for the long-range, medium-range, and short-range classifications shown in table 4.10. (**3**) These figures are from table 4.7, col. 2, for those comparisons where several years of alternative net revenue data are available. Figures for the other comparisons not shown in table 4.7 come from table 4.6, col. 8. (**4**) This is the ratio of the used aircraft price of the new model to the used aircraft price of the old model in the same comparison. In each case, the figure shown is the ratio of the price shown for each model in table 4.9, averaged over the years in that table where a price estimate or quotation for both models is available. For instance, table 4.9 shows that a price comparison for the A-300 with the L-1011 is available only for 1982, whereas a price ratio between the DC9-30 and DC9-10 can be established for three years, 1972, 1977, and 1982. In those cases where both a price estimate and a price quotation are available for both models in a given year, the quotation is always used in preference to the estimate. In several comparisons, the "new model" was so new that no price quote or estimate was available. In these cases, the used price was estimated as the new aircraft price for that year (from table 4.6). Since the new aircraft prices do not include engines, allowing 25 percent of the value of the airframe for engines would imply that these proxy prices are 80 percent of the price of the new aircraft. Used prices were estimated in this way for the following models and years: B-767 (1982), DC8-50 (1965), B727-100 (1965), B-720B (1965), and DC9-10 (1965). (**5**) This is calculated in the same way astable 4.6, col. 6, with the used aircraft price ratio in col. 4, u_1/u_0, substituted for the net revenue ratio n_1/n_0. (**6**) The years of transition are those used in table 4.11 to phase in the relative price changes shown in table 4.10. In each case, they are pairs of years, with the first chosen to be the initial year when significant deliveries were made to domestic trunk airlines. Weights were established for particular aircraft in a particular generation by taking its share of total sales in the relevant category. Source for numbers of aircraft sold by model is *Aerospace Facts and Figures,* issues dated 1961, 1969, 1974/75, and 1981/82. Source for average price of each model is the set of worksheets underlying table 4.2.

[a]The extreme value for 1982 is omitted.

implied by the net revenue ratios and used price ratios are indicated in columns 3 and 5, respectively.

The task of converting the relative price changes in columns 3 and 5 into Törnqvist price indexes is carried out in two steps, the first of which is to determine weighted average relative price changes within the three length-of-haul categories, and the second of which determines the weighted average of these three sets of price changes. The first step allocates the relative price changes between old and new models to pairs of "transition years,"chosen as the first two years of production of the new model. The choice of two transition years, rather than one, helps smooth the final price index and also takes account of the fact that production may continue on the last few aircraft in an older generation after production has started on the first aircraft in the new generation. Then a weight, based on the value of production, is determined for each model within its "generation" of long-haul, medium-haul, or short-haul aircraft. In several cases, this is straightforward, since there was only a single model in a given generation, and it can be allocated a weight of 100 percent. In other cases, there are several models within a given generation, as for the third generation of long-haul aircraft comprising the L-1011, DC-10, and B-747, and weights based on the value of production are determined by the share of each aircraft in the total production run of its generation (1970–77 for long-haul generation 3, and 1961–66 for medium-haul generation 2). When a previous generation remains in production, the weights on the next generation do not sum to 100 percent, as in the case of the short-range DC9-30 and B737-200, which were produced simultaneously along with the newer DC9-50, and the long-range B707-100 and B707-300, which remained in production along with the stretched DC8-61.

The weights shown in column 6 of table 4.14 then determine the relative price change within each length-of-haul category for each year. As an example, the "third generation" DC9-50 is allocated a weight of 20 percent in the short-haul category. The relative price change between the second and the third generations based on net revenue data from table 4.9 is indicated as −50.6 percent in column 3. Thus, the price change on the net revenue basis for the short-haul category in the two transition years 1978–79 is calculated as (−.506)(.2)(.5), which equals −5.06 percent. On the used price basis, the relative price change in column 5 is indicated as −49.1 percent, implying a corresponding price change in the short-haul category for 1978–79 of −4.91 percent. In years between transition years for each category, the relative price change is set equal to zero. Thus, in the short-haul category, the relative price change on the net revenue basis is calculated as −37.9 percent for 1966–67, −14.35 percent for 1968–69, −5.06 percent for 1978–79, and zero for all other years between 1958 and 1983. Since no data are available to make model comparisons on either the net revenue or the used price basis before 1958, assume zero relative price change in all three categories for the period 1947–57.

Table 4.15 **Two "Real" Price Indexes for Commercial Aircraft and Weights by Category, 1957–83**

	Value Weights (Percent)			Real Price Indexes	
	Long Range (1)	Medium Range (2)	Short Range (3)	Net Revenue Basis (4)	Used Price Basis (5)
1983	51	32	17	0.78	0.65
1982	33	38	29	0.82	0.77
1981	45	36	18	0.88	0.90
1980	68	19	14	0.88	0.90
1979	63	24	13	0.88	0.90
1978	53	34	14	0.93	0.92
1977	55	30	15	0.97	0.94
1976	66	17	18	0.97	0.94
1975	60	22	19	0.97	0.94
1974	65	19	16	0.98	0.95
1973	75	19	6	1.00	0.97
1972	78	11	11	1.00	1.00
1971	78	8	14	1.02	1.10
1970	76	10	14	1.18	1.39
1969	37	22	41	1.35	1.63
1968	37	25	38	1.42	1.83
1967	40	26	34	1.69	2.36
1966	37	46	17	2.18	3.18
1965	46	52	2	2.33	3.39
1964	39	61	. . .	2.31	3.92
1963	53	47	. . .	2.28	4.66
1962	55	45	. . .	2.29	4.66
1961	35	65	. . .	2.32	4.82
1960	80	20	. . .	2.39	5.06
1959	67	32	1	3.91	8.02
1958	48	47	5	6.73	13.23
1957	. . .	. . .	. . .	7.83	15.11

Sources by column: (1–3) Same as table 4.10, col. 6. (4) Relative price changes from table 4.10, col. 3, phased in during the transition years shown in table 4.10,col. 6, using the weights shown in the same column. (5) Same as col. 4, using relative price changes from table 4.11, col. 5.

The second step is to convert these relative price changes within the three length-of-haul categories into two aggregate real price indexes, one on the net revenue basis and one on the used price basis. Weights based on the value of production for each of the three categories are exhibited in the first three columns of table 4.15.[14] These weights are used to combine the relative price changes for the three length-of-haul categories into the two Törnqvist indexes displayed in columns 4 and 5 of table 4.15. As we might expect, the most rapid decline in both real price indexes occurred in 1958–60, as a result of the replacement of the piston DC-6 and DC-7 series by the turboprop Lockheed Electra (L-188) and the pure jet Boeing 707 and

14. Sources for the value of production are the same as those listed in the notes to col. 6 of table 4.14.

720, and the Douglas DC-8. Both indexes also decline rapidly during the period of the introduction of the first short-haul jet airliner, the DC9-10, in 1966–67, and the introduction of the stretched DC8-61, B727-200, and DC9-30 in 1967–69. There is little further decline in the net revenue index, while there is a substantial further decline after 1970 in the index based on used aircraft price ratios. This discrepancy reflects the greater quality differential attributed by the used price method to the long-range DC-10 and L-1011. An even greater discrepancy occurs between 1963 and 1966, because the used price method rates the medium-range B727-100 as much higher in quality than the L-188 that it replaced, whereas the net revenue method places no value on passenger time or comfort and treats the two aircraft as comparable. The fact that the L-188 was retired from trunk airline service by the late 1960s, whereas several hundred B727-100 aircraft were still in trunk airline service in 1985, suggests that the net revenue method is too conservative in this example. A straightforward way to summarize the two different real price indexes is to display their annual percentage rates of growth before and after 1972:

	Net Revenue Basis	Used Price Basis
1957–72	−12.8	−16.6
1972–83	−2.2	−3.8

Table 4.16 (as well as Fig. 4.1) displays four nominal price indexes for commercial aircraft. The SMSA and BEA indexes are copied from table 4.3 and refer to identical models, with no attempt to measure the price change that occurs when one model is replaced by another. The two new indexes consist of the SMSA index for identical models multiplied by the two real price indexes from table 4.15, one on the net revenue basis and one on the used price basis, that measure the change in price between one model and its replacement. Overall, the two new indexes provide a radically different verdict on price changes in the commercial aircraft industry than do the SMSA and BEA indexes, which implicitly ignore nonproportional quality change between old and new models. The difference between the SMSA and the BEA indexes appears to be minor when compared to the enormous contrast with the two new indexes, and between the two new indexes themselves.

4.8 Conclusion

A review of the estimation procedures suggests little reason to doubt the overall implications of the index based on used aircraft price ratios, although

Table 4.16 **Nominal Price Indexes for Identical Models and After Adjustment for Quality Change (1972 = 100)**

	SMSA Index (1)	BEA Index (2)	Net Index Net Revenue Basis (3)	New Index Used Price Basis (4)
1983	223.4	253.3	174.3	158.6
1982	217.3	247.8	178.2	173.8
1981	195.4	224.1	172.0	173.9
1980	177.8	204.3	156.5	158.2
1979	161.5	182.2	142.1	143.7
1978	152.1	163.6	141.5	138.4
1977	139.3	152.2	135.1	129.6
1976	125.1	138.8	121.4	116.3
1975	116.0	123.4	112.5	107.9
1974	108.9	115.2	106.7	103.5
1973	103.6	104.1	103.6	100.5
1972	100.0	100.0	100.0	100.0
1971	98.8	98.1	100.8	108.7
1970	94.8	94.0	111.9	137.5
1969	91.9	88.7	124.1	162.7
1968	89.7	85.6	127.4	176.7
1967	87.0	83.0	147.0	219.2
1966	86.9	80.0	189.4	283.3
1965	86.2	78.7	200.9	297.4
1964	84.7	77.1	195.7	330.3
1963	83.0	78.7	189.2	374.3
1962	79.9	75.5	183.0	360.4
1961	79.4	73.2	184.2	369.2
1960	80.4	82.3	192.2	389.9
1959	78.3	72.1	306.2	592.7
1958	78.0	69.6	524.9	954.7
1957	78.2	68.5	612.3	1,087.8
1956	77.7	65.2	608.4	1,080.8
1955	77.4	59.8	598.2	1,062.7
1954	74.2	57.5	581.0	1,032.1
1953	69.6	56.8	545.0	968.1
1952	66.4	55.6	519.9	923.6
1951	61.9	55.9	484.7	861.0
1950	64.1	49.0	501.9	891.6
1949	56.6	46.5	443.2	787.3
1948	54.0	44.7	422.8	751.1
1947	53.9	41.9	422.0	749.8

Sources by column: (1–2) Table 4.3, cols. 2 and 3. (3–4) Table 4.3, col. 1, times table 4.11, cols. 4 and 5.

there is obviously a margin of error in the sense that different data sources and different choices of weights and transition years would influence the final price index. But it is hard to "argue with the market," especially with the basic fact that the used price ratio of new to old models is much higher than the ratio of their prices when new. And the fact that these ratios of used aircraft prices widened rather than narrowed over time, despite the narrowing

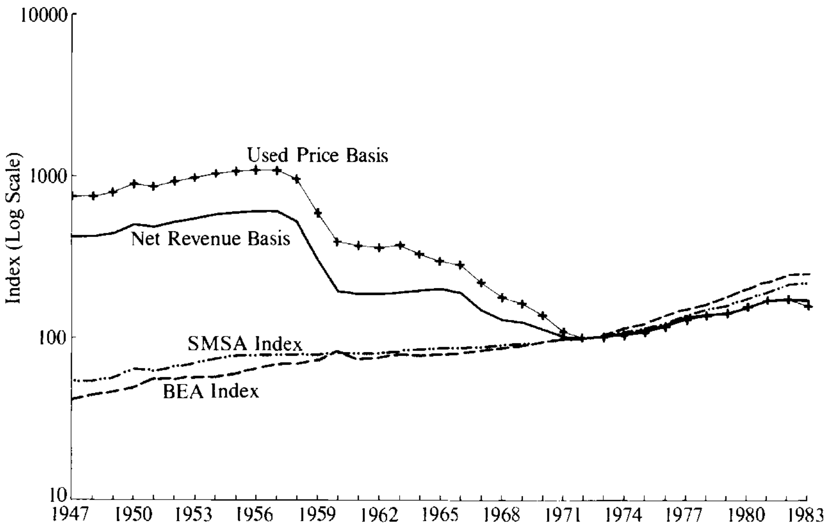

Fig. 4.1 Indexes of new aircraft prices, 1972 = 100

relative difference between the ages of the new and the old models, suggests that economic depreciation dominates any minor effect of physical depreciation in the used aircraft market.

As for the net revenue ratios, they are more likely to be too conservative, in the sense of attributing too little rather than too much net revenue advantage to the newer models and thus understating the rate of relative price decline. As several of the examples above suggested, the net revenue method understates the advantage of new models by placing no value on passenger time or comfort, and by assuming that the expected lifetime of all models is the same. Likewise, no value is placed on intangibles like reliability, in contrast to the market contrast in reliability of piston and jet aircraft suggested by the following quote: "In the piston era, experience showed a dual engine failure rate of one per 8 million operating hours, compared with a 'probability rate' of one per 1 billion hours for jet transports. There is so far no recorded instance of such a dual failure in 25 years of jet operations" (*Aviation Week and Space Technology*, 17 December 1984, 24).[15] Yet speed, comfort, and reliability can all be valued by the used aircraft market, and on average the ratios of used aircraft prices between new and old models are greater than the corresponding net revenue ratios.

15. Another achievement of modern jet technology has been witnessed as two-engine jet aircraft have been allowed to fly the North Atlantic. As reliability has been proven, the rules for the number of minutes these aircraft can remain away from the closest airport have been extended. As of mid-1989, there has been no single instance of an engine failure on a two-engine jet aircraft since such flying began in 1985.

Table 4.17 **Comparison of Growth Rates of Various Indexes of Prices and Employee Compensations, in Annual Percentage Growth Rates**

	1947–72	1972–83
1. Compensation per FTE employee	6.3	8.6
2. BEA price index	3.5	8.8
3. New index net revenue basis (NRB)	−5.6	5.2
4. New index used price basis (UPB)	−7.7	4.3
5. Addenda: Comparison-BEA	2.8	−0.2
6. Addenda: Comparison-NRB	11.9	3.4
7. Addenda: Comparison-UPB	14.0	4.3

Sources: Rows 1–4 from table 4.16. Rows 5–7 from table 4.1.

One subtle source of error may create a further presumption that the net revenue technique understates the advantage of new models. Consider the amazingly high ratios of net revenue to aircraft price arrayed in table 4.8, column 4, ranging as high as 60 percent. This is far higher than the likely cost of capital and makes us wonder why the airline industry has not been more profitable. One possibility is that the approach used in tables 4.8 and 4.9 may systematically overstate revenue or understate costs, leading to exaggerated estimates of net revenue. If this tendency were corrected, all net revenue figures would be squeezed, and the older planes would be pushed closer to break-even status, thus increasing the relative net-revenue advantage of the newer models. Another important source of conservatism in the estimates is the decision to use the same utilization rates for new and old models. The actual utilization rates for piston aircraft were uniformly lower than for jets, allowing them to earn even less net revenue than indicated in my calculations. One hopeful note is that the net revenue earned on the older models declines over time and becomes negative at roughly the date when these aircraft were retired from U.S. trunkline service, for example, the estimated net revenue of the B707-300 becomes negative in 1982, about the same time that this model was phased out by the last airlines using it (American and TWA) in 1981–83.

This chapter began with the working hypothesis that the official BEA index for equipment cost overstates aircraft price increases more before 1972 than afterward, leading to a corresponding understatement of the growth rate of real equipment investment and the real capital stock of aircraft. The observed post-1972 slowdown in the growth of labor productivity in the airline industry thus might be partly explained by a slowdown in the growth rate of capital input that is greater than is implied by official equipment price indexes. The chapter supports the hypothesis and yields two new price indexes for aircraft that decline in nominal terms before 1972 and rise thereafter. An interesting contrast is provided by the juxtaposition of the growth rates of the various price indexes from table 4.16 with the growth rate of employee compensation from table 4.1, listed in table 4.17. Thus, according to either of the new indexes, the incentive to substitute capital for labor was much greater before 1972 than afterward, and the BEA index understates this post-1972 shift by a wide margin. It remains to be seen whether studies of other major capital goods indicate a similar tendency for a greater overstatement of price increases prior to 1972 than afterward.

To the extent that this study "explains" the slowdown in productivity growth in the airline industry by the mismeasurement of nonproportional quality change in the production of aircraft, it just shifts the puzzle of the productivity slowdown back one industry from airlines to aircraft manufacturing. At the beginning of this chapter, I suggested that, if profit margins were constant, then the difference in the growth rates of compensation per employee and in equipment cost could serve as a proxy for productivity growth in the aircraft manufacturing industry. As shown by table 4.17, the difference between compensation per employee and the two new equipment price indexes (NRB and UPB) is much greater than for the BEA equipment price index. This difference decelerated after 1972 by 8.5 points according to the NRB index and by 9.7 points according to the UPB index, as contrasted to a slowdown of 3.0 points according to the BEA index. The leading hypothesis to explain this slowdown in the rate of nonproportional quality improvements is Nordhaus's (1982) "depletion hypothesis." The aircraft airframe and engine industry had no "bag of tricks" to match the discovery of the jet engine and the swept-back wing, and many of the quality improvements made after 1960 took the form of making aircraft larger. But the limit was reached with the Boeing 747 and Douglas DC-10, and it is likely that we will be traveling in those aircraft (or slightly improved versions thereof) well into the twenty-first century.